RIVERS STATE UNIVERSITY, PORT HARCOURT

THE INDISPENSABLE CREATION IN OUR PLANET

AN INAUGURAL LECTURE

By

PROF. ONOME AUGUSTINA DAVIES (NEE BUBU)

B.Sc. (Hons) (Zoology), M.Sc., Ph. D. (Hydrobiology & Fisheries) (UI, Ibadan)
FAWARD, FNFP, MFISON, MZSN, MAASN, MWAS

Professor of Hydrobiology & Fisheries

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Dedication

This inaugural lecture is dedicated toThe Almighty God,
my power and strength, my parents,
Late Pa Joseph Didemise Bubu
and
Mrs. Clara Patricia Bubu (Nee Dafe)
for giving me sound education.

discussant on NTA Port Harcourt programme on aquaculture, facilitator at Fisheries workshops and seminars organized by different organizations in Nigeria, coordinator of enlightenment programmes on fish farming in Nigeria. Prof. Onome Augustina Davies is the Director of ROONE Ventures Agro-Business Consults. She is member of the following learned societies: World Aquaculture Society, Fisheries Society of Nigeria (National and Rivers State Chapter), Zoological Society of Nigeria, Association for Aquatic Sciences of Nigeria, American Society of Agricultural and Biological Engineers, Nigerian Women in Agricultural Research Development (NiWARD) and Multidisciplinary Aquatic Studies Team. Prof. Onome Augustina Davies loves singing Christian hymns and songs, listening to Christian music and reading of English literatures. Prof. Onome Augustina Davies established Pa Joseph Didemise Bubu Educational Foundation, Salem Baptist Church, her local church in Ibadan, in honour of her late Father in February 2011. The foundation assists children from very poor background for annual payment of external examinations (O/L WAEC and NECO).

Prof. Onome Augustina Davies is a committed member of the Foursquare Gospel Church (FGC), Rivers State where she had held different positions namely: Coordinator of Foursquare Gospel Church, Abuloma I, Secretary to the Council of the Foursquare Gospel Church, Abuloma I, Sunday School Teacher (Adults Class) Foursquare Gospel Church, Abuloma I and Women Adviser/Member of Foursquare Women International (FWI) Foursquare Church, Abuloma I. She is currently a church worker in Foursquare Gospel Church, Ogu, Ogu/Bolu Missionary Zone, Rivers State.

Prof. Onome Augustina Davies is happily married to her best friend and lover, Engr. Dr. Oluwadurotimi Moses Davies (Associate Professor of Agricultural Engineering and Sub-Dean, Faculty of Engineering, Niger Delta University) and blessed with 5 children (including a set of identical twins); Architect Oluwadamilola Oghenerukevwe Ayomide, Engr. Iyinoluwa Esegbuyotaroghene Emmanuel, Miss Oluwasijibomi Ogheneruona Glory, Oluwadabobomi Oghenerhuarho Grace and Ojurereoluwa Esiroghene Toluwalase **Davies.**

Faculty Representative, Curriculum and Instructions Committee (January 2016- October 2016), 2016 ELECO Member and 2018 ELECO Chairman, RSU ASUU. She is currently the Chairman, Senate Curriculum and Instruction Committee (C&I). Nevertheless, she is the current Treasurer of the Academia Welfare, Co-operative Investment and Credit Society Limited of the Rivers State University Academic Staff Union of Universities.

She has won several prestigious awards and honours. She is a Post Doctorate fellow of the African Women in Agricultural Research and Development (AWARD) (the first Nigerian Fisheries Scientist Post-Doc AWARD Fellow), a programme sponsored by United State Agency on International Development (USAID) as well as Bill and Mellinda Gates Foundation and Netherland Fellowship Programme (NFP), a programme sponsored by Netherlands Government as well as CTA fellow, a programme sponsored by Technical Centre for Agricultural and Rural Cooperation ACP-EU. One of her works was recognized by the Chicago Council on Global Affairs- Recognition for contribution to the project "Girls Grow: A Vital Force in Rural Economies" - Great synopsis of AWARD Fellowship.

Outside the University Community, She is involved in quite a number of community services. Prof. Onome Augustina Davies (Nee Bubu) has been appointed external examiner and assessor to Ahmadu Bello University, Zaria, Kaduna State, Federal University of Agriculture, Abeokuta, Ogun State, Niger Delta University, Amassoma, Bayelsa State and Michael Opara University of Agriculture. She is also a Resource Person to National University Commission (NUC) on accreditation of programmes in universities. She is currently the Editor-in-Chief, Journal of Aquatic Sciences (a journal published by Association for Aquatic Sciences of Nigeria (AASN) and Co-Chairperson of King Alfred Diete-Spiff University (KADU) Implementation and Planning Committee. She is also the Regional Editor, Research Journal of Applied Sciences, Engineering and Technology- Maxwell Science Publication, U.K., peer reviewer to FISON and many international journals, live discussant on RSTV programme (Globe in 60 minutes) on shrimp culture as non-oil generating venture for youth engagement in the Niger Delta, live

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- Women Leadership and Managerial Course. Addis Ababa, Ethiopia 19-25 September 2010. **AWARD SPONSORED**.
- Surat Thani Shrimp Farmers Club Seminar, Wang Tai Karaoke Hotel, Surat Thani, Thailand, 12-13 February, 2011. **AWARD SPONSORED.**
- Aquatic Asia Conference and Exhibition in co-location with VIV Asia, BITEC Bangkok, Thailand, 9-11 March, 2011. **AWARD SPONSORED.**
- Web 2.0 and Social Media for Learning Opportunity Training Workshop, University of Port Harcourt, Nigeria, 20-24 October, 2014. **Technical Centre for Agricultural and Rural Cooperation ACP-EU (CTA) SPONSORED.**

Prof. Onome Augustina Davies (Nee Bubu) has wealth of experience in university administration. She served as Member of Committee on proposed Centre for Continuing Education Programme (1999-2010), Assistant Departmental Examinations Officer (1999-2004), Undergraduate Seminar Coordinator (2000-2004), Undergraduate Project Coordinator (2000-2004), Staff Seminar Coordinator (2001-date), Staff Seminar Coordinator (2001-date), Secretary of Departmental Committee on Revised Postgraduate Programme (2004), Member of Faculty of Agriculture Students Disciplinary and Advisory Committee (2002-2005), Departmental Examinations Officer (2004-2008), Deputized Acting Head of Department (2008-2010), Secretary, Departmental Postgraduate Board (2008-2009), Undergraduate Project and Seminar Coordinator (2008-2012), Chairman, Departmental Postgraduate Board (2009-2012), Chairperson, ISS Teaching Farm (a subcommittee of ISSMC) (2011-2012), Member, International Secondary School Management Committee (ISSMC), Rivers State University of Science and Technology, Port Harcourt, Rivers State (2011-2012), Chairperson, the Aquaculture Centre Management Committee, Department of Fisheries and Aquatic Environment, Rivers State University of Science (2012-2017), Departmental Academic Adviser (2012-date), Faculty of Agriculture Representative at Senate (2012-2013), Chairman, Departmental Laboratory Committee (2015-date), State University of Science and Technology) in the Department of Fisheries and Aquatic Environment (formerly known as Department of Fisheries) and rose through the ranks to the rank of a Professor. She has supervised a number of Ph.D., M. Sc., PG. D. and B. Sc. students. Prof. Onome Augustina Davies (Nee Bubu) has over hundred articles in reputable referred local and international journals as well as referred conference proceedings, 97% of which appeared in indexed journals and a chapter in book. Her scientific papers are widely cited by African Journal Online (AJOL), Academia, Academix, Google Scholar, Scopus and Research Gate. Prof. Onome Augustina Davies (Nee Bubu) increased the visibility of the Department of Fisheries and Aquatic Environment in the Rivers State University Campus between 2004 and 2012 through the production and sales of live and dried catfish as well as all-male tilapia.

She had attended many local and international conferences, workshops and courses.

International Conference, Workshops and Course attended are:

- Mentoring Orientation Workshop, Mombasa, Kenya, 14th-18th September, 2009. **AWARD SPONSORED.**
- International Foundation of Science/Universite Eduardo Mondland/AWARD Scientific Writing and Policy Development in Agricultural Research Workshop, Maputo, Mozambique, 16 – 27 January, 2010. **AWARD SPONSORED.**
- Competing Claims Course on natural resources, Wageningen UR Centre for Development Innovation, Wageningen, Netherlands, 22 February-5 March, 2010. **NETHERLANDS GOVERNMENT SPONSORED.**
- ToR–F09/M09 AWARD Progress Monitoring Meetings 2010, NOVOTEL Hotel,Accra, Ghana, 20-21April, 2010. **AWARD SPONSORED.**
- Australasian Aquaculture International Conference and Trade Show, Hotel Grand Chancellor, Hobart, Tasmania, Australia, 23rd-26th May, 2010 **AWARD SPONSORED.**

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Biodata OF

PROFESSOR ONOME AUGUSTINA DAVIES (NEE BUBU)

Prof. Onome Augustina Davies (Nee Bubu), an internationally visible Professor of Hydrobiology and Fisheries hails from Aragba-Okpe Town in Okpe Local Government of Delta State and was born on the 25th August, 1970 in Ibadan, Oyo State to Late Papa Joseph Didemise Bubu (a.k.a Papa Guy) of Aragba-Okpe Town in Okpe Local Government and Mama Clara Patricia Bubu (Nee Dafe) of Abraka Town (University Town), Ethiope East Local Government, all in Delta State. She is the 8th child out of eleven children and 5th daughter of her parents. She is the first female Professor in the Department of Fisheries and Aquatic Environment, Rivers State University and also in the entire families of Bubu, Dafe and Davies. Also, she is a mentor to many people including students within and outside the Rivers State University of Science. Her life purpose is to fight poverty, hunger and unemployment in Nigeria and Africa by boosting fish production through sustainable aquaculture and capture fisheries.

Prof. Onome Augustina Davies (Nee Bubu) attended Abadina Primary School 1, University of Ibadan between 1976 and 1982 and Onireke High School, Link Reservation, Ibadan between 1982 and 1987. She had her B.Sc. (Hons) Zoology in 1991, M.Sc. Hydrobiology and Fisheries in 1994 and Ph.D. Hydrobiology and Fisheries in 2008, all degrees from the premier University of Ibadan, Oyo State, Nigeria. Prof. Onome Augustina Davies (Nee Bubu) had a post Doctorate Programme at Shrimps Genetic Improvement Centre, Phumriang, Chaiya, Surat Thani, Thailand in 2011.

She did the primary assignment of the mandatory one year National Youth Service (NYSC) programme at Federal Government Girls College (FGGC), Abuloma, Port Harcourt as Biology and Integrated Science Teacher. She started her academic career as Assistant lecturer on 29th January 1996 with the Rivers State University (formerly known as Rivers

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The Vice-Chancellor

Deputy Vice-Chancellor

Registrar and other Principal Staff of the University

Provost of the College of Medicine

Dean of Post Graduate School

Deans of Faculties

Professors, Directors of Institutes and Heads of Departments

Staff and Students of Rivers State University

Distinguished Ladies and Gentlemen

1.0 PREAMBLE

It is with great honour, privilege and humility that I stand before this august audience to deliver the 57th inaugural lecture of this prestigious and outstanding University on behalf of the Faculty of Agriculture. This is also the second inaugural lecture from the Department of Fisheries and Aquatic Environment. Mr. Vice-Chancellor Sir, permit me to borrow a leaf from the Thai people that first worship their god, Buddha and King before starting a programme, be it academic or non-academic, by singing this worship song ***"Thou art worthy O Lord, worthy O Lord, to receive glory, honour and power (and power), for thou hast created all things and for thy pleasure they are and were created (Revelation 4 verse 11) (3xs).***

My Education

I am a product of a humble beginning. I give God all the glory for using my Late Father, Pa Joseph Didemise Bubu to send me to school against his late father's advice not to educate female children. This mentality was popular then as the belief that female children would always end up in their husbands' kitchens. He was influenced positively by a Baptist Missionary, the Late Reverend Ethel Harmon of Cabin, USA who took him from his village, Aragba-Okpe Bendel State (now Delta State) in 1949 to Ibadan where he served her as Secretary in the Sunday Department of the Nigerian Baptist Convention Office, Ibadan, for a period of ten years before he got married and worked at the University of Ibadan, Ibadan. My father with the unflinching support of my mother, Mrs. Clara Patricia Bubu sponsored my education from primary to master's degree level and today by God's mercy and faithfulness, I am a Professor. He was well rewarded by that godly and excellent decision before and after death. He witnessed my Ph.D. convocation on 14th November, 2008. At death, he was very great and well known in February 2010 when I was in Netherlands for a short course on "Competing Claims on Natural Resources". A programme fully sponsored by the Netherlands Government under the Netherlands Fellowship Programme (NFP). A condolence register was opened for him with many condolence messages from participants from many countries and the Dutch lecturers. You can see that it really pays to invest in female children's education. Also, that decision had produced Professor Onome Augustina Davies (**Nee BUBU**), the first female Professor of Hydrobiology and Fisheries of this great University, first Fisheries Scientist Post Doctorate Fellow of The African Women in Agricultural Research and Development (AWARD), a fellowship sponsored by Bill and Mellinda Gates Foundation and United States Agency for International Development (AWARD) and first Professor from my village, Aragba-Okpe, Delta State.

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I aspired to be an Agriculturist and University lecturer right from my secondary school days. Keen interest in Agriculture was ignited as a growing child in primary school, when my siblings and I used to follow our parents to their farm at the Botanical Gardens, University of Ibadan, Ibadan, Oyo State. I thank God for the Guidance and Counselor of my secondary school, Onireke High School, Ibadan who identified my strength in agriculture and patiently guided me into the right profession. My choice of discipline was not without opposition by my first brother who wanted me to study Medicine and Surgery because of my excellent academic performance. I was therefore asked to choose University of Ibadan, Ibadan as first choice and second choice for Medicine and Surgery but God Almighty used the Joint Admission Matriculation Examination Board (JAMB) and Late Prof. F.M.A. Ukoli (Renown Parasitologist in Nigeria) to redirect my path to Agriculture by studying Zoology. My father was told I would be allowed to change to Medicine and Surgery after Year One once I am on good standing with high CGPA. Unfortunately Zoology Department refused to release me to Department of Medicine and Surgery despite my high CGPA and clear standing due to a new "change policy". At this stage, I was allowed to continue with my chosen career, "Zoology" and I discovered in Year Two that I can still be an Agriculturist if I specialize on Entomology (study of insects) or Hydrobiology and Fisheries. My B.Sc. Project was in Parasitology titled "Studies on the parasitic fauna and food contents of gastro-intestinal tract of the common African toad *Bufo regularis* in the University of Ibadan Campus, Ibadan, Nigeria" supervised by Dr. Alexander B. Odaibo (now Prof. Alexander B. Odaibo, Renown Parasitologist) and Academic Seminar on Entomology titled "Insect pests of economic crops in Nigeria" supervised by Late Prof. Afolabi Toye (Renown Entomologist and first Vice-Chancellor, University of Ilorin). **At the end of my first degree I decided to specialize on Hydrobiology and Fisheries for my master's and Ph.D. degrees because of the indispensable nature of water and fish to mankind.**

My M.Sc. thesis was on Aquaculture titled "Artificial spawning of *Clarias gariepinus* (Hogendoorn & Vismans, 1980) using ovaprim synthetic hormone and its larval rearing" supervised by Dr. Alexander O. Ugwumba (now Prof. Alexander O. Ugwumba, Renown Hydrobiologist and Fisheries Scientist/ Environmental Scientist). My academic seminar was on Aquaculture titled "Water quality: Its consequences for the profitability in fish farming" supervised by Prof. S. O. Fagade (Renown Hydrobiologist and Fisheries Scientist/ Environmental Scientist). My Ph.D. thesis was on Hydrobiology titled "Physico-chemical parameters, plankton, epiphyton and finfish assemblages of Okpoka Creek, Niger Delta, Nigeria" and Post Doctorate on Aquaculture titled "**Domestication and selective breeding program of the black tiger shrimp *Penaeus monodon" at*** Shrimp Genetic Improvement Centre, Phumriang, Chaiya, Surat Thani, Thailand. All my supervisors mentored me to who I am today.

My Academic Career

My appointment as a lecturer (Assistant Lecturer in 1996) to the Department of Fisheries and Aquatic Environment (formerly known as Department of Fisheries) of this University was divinely arranged by God using Late Dr. S.S. Ovuru (the then Mr. S.S. Ovuru), Late Chief M.B. Inko-Tariah (the then Head of Department, Fisheries) and Prof. M.S. Igben (then then Dean of Faculty of Agriculture) in my favour. Dr. A.D.I. George (the then Mr. A.D.I. George) was God's Courier Agent to deliver my interview and appointments letters respectively, Rev. Engr. Olufemi Timothy Ayodele was my Divine Mail Box to receive the interview letter and Pastor (Mrs). Funmi Oseyemi, my Divine Nanny, that took care of my two weeks old baby-friendly baby (my first child) when I went for the interview. I am not meant to serve in the former Department of Biological Sciences. "*No employment*" said the then Head of Department, Dr. T. G. Sokari (now Prof. T.G. Sokari) in February 1995. Consequently, I moved to the Department of Fisheries where God Almighty had destined me to be

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and not to University of Port Harcourt as Faculty of Science was then relocating to Abuja Campus from Choba Campus hence I came to submit my application letter to Fisheries Department of Rivers State University of Science and Technology (now Rivers State University) in February 1995. Since then, there have been no regrets as God's mercies have assured my elevation from one level of glory to another. His Grace and Faithfulness are forever adequate for me. I am a biological steward functioning as a biological accountant, auditor, reviewer, analyst, monitor, manager, culturist, protector and trainer.

What is an Inaugural Lecture?

Inaugural Lectures are given by newly-promoted or appointed professors. It is an ideal opportunity for new professors to introduce themselves and to present an a brief summary of their own contributions in their field to their academic peers, students and research collaborators. It is also an excellent way to present and emphasize the latest developments in a discipline to an audience consisting of both members of the University and a wider general public. It can also be a time to celebrate an important personal landmark with family, friends, mentors and colleagues; and for the University to celebrate and showcase the academic achievements of its staff.

This inaugural lecture will therefore cover:

1. Indispensable substance of our planet (i.e dynamic waters), I will elucidate what is water?, why water and fish are indispensable, man, steward of indispensable creation on earth
2. Aquatic environments (Types, properties, functions, what is dynamic aquatic environments?, causes of dynamic aquatic environments, types of studies on aquatic environments)
3. Nigerian inland waters (Nigerian aquatic environments, major water resources of Nigeria, major biological resources of Nigeria (aquatic plants, animals and wetland wildlife

resources), physical, chemical and biological properties of aquatic environments, plankton and periphyton as biomonitors and bioindicator of pollution, and some human activities affecting the Nigerian inland waters).

4. My contributions to knowledge are in the areas of:

- Hydrobiology and Limnology including studies on phytoplankton, periphyton, zooplankton, physico-chemical parameters and sediment parameters
- Fisheries (Fisheries Biology and Management)
- Fish production through aquaculture
- Organic aquaculture (organic buffers)
- Heavy metals and aromatic hydrocarbons (PAHs) studies in aqua-environments
- Bacterial pollution studies, Impacts of sand dredging studies on aquatic life
- Renewable energy (studies on utilization of aquatic plants as a source of renewable energy)
- Playing the role model to students and being part of the strategists that helped increase the enrollment of students in the Department of Fisheries and Faculty of Agriculture
- Establishment of Cottage Fish Farm at ISS
- Donation of all male tilapia, *Orechromis niloticus* seeds
- Mentoring
- Editorship of reputable journals
- Having Chapters in research books
- Minor productive works
- Research fellowships and recognition of works

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- Chairmanship of Senate Curriculum and Instructions Committee
- Training of skilled fish farmers

2.0 INTRODUCTION

2.1 Indispensable creation of our planet

Let me start by revealing from the onset that my indispensable substance of life is nothing other than water. Primordial life has been demonstrated to commence in anan aqeous environment billions of years ago. Water covers seventy-five percent (75%) of the earth's surface including the ice-covered areas. The whole earth sits on waters. The earth was called "the planet of water" as described in Genesis Chapter 1verse 2 of the Holy Bible (AKJV), "And the earth was without form, and void; and darkness was upon the face of the deep. And the spirit of God moved upon the face of waters. Genesis Chapter 1 verses 9-10 say "And God said, 'Let the waters under the heaven be gathered together unto one place, and let the dry land appear: and it was so'. And God called the dry land **Earth**; and the gathering together of the waters called the **Seas**: and God saw that it was good". The general name for the waters is **seas** according to the bible. These waters accommodate different living creatures (plants and animals) from the unicellular to the most advanced multicellular ones (Genesis Chapter 1 verse 20[a], "And God said, Let the waters bring forth abundantly the moving creatures that hath life") as well as non-living components (sediments and abiotic properties). All the living creatures in the waters are known as **fish** (Genesis Chapter 1verse 26[a]). The waters, fish and their non-living components are dynamic in nature. Nigeria is richly blessed with many dynamic waters and biological resources which are very important and indispensable to humanity. This inaugural lecture is written to provide good insight into why these waters (fresh, brackish and marine), fish and their constituents are indispensable on earth and to man while also educating us on the reasons for the changing waters.

2.2 What is water?

Water is the most abundant natural resource and most important chemical compound responsible for the existence of living organisms on earth. It is a transparent, tasteless, odourless, and nearly colourless chemical substance that is, the main constituent of earth's habitats for water (aquatic) organisms such as rivers, streams, lakes, creeks, swamps, lagoons, and oceans (Davies and Ansa, 2010; Davies, 2014), and the fluids of most living organisms. The human body is made of 70% of water. It supports the activities of living organisms on earth in different forms: the solid (ice), liquid, and gaseous (vapour) states at the surface temperature and pressure of the earth. Water on earth circulates continually through the water cycle and occurred in lakes, bays, oceans, glaciers and underground suppliers where the rate of movement is relatively low. Water is life, vital for all known forms of life and an integral part of our spiritual existence. The distribution of water in aqua sphere and average residence period is shown in Table 1.

Table 1: Distribution of water in aqua sphere and average residence period

Category	Volume (10^3 km^2)	Percentage (%)	Average residence period
Ocean	1,338,000	97	3,700 years
Polar eternal ice/glacier	24,100	1.7	16,000 years
Underground water	23,400	1.7	300 years
Fresh water lake	91	0.007	10–100years
Salt water lake	85	0.006	10–10,000 years
Soil water	16.5	0.001	280 days
Water vapor	12.9	0.001	9 days
River	2.12	0.0002	12 – 20 days

Source: Furuya and Yasuda (2017)

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2.3 Why water and fish are indispensable

Water, a polar molecule (positive and negative charges), is the most abundant component of any living organism for its survival and well being thus it is indispensable. The human cells contain approximately 80%. Water affects the physiology of all living organisms (**Davies** and Ansa, 2010; Kwen, **Davies** and Okaeme, 2012): growth (plant growth, seed germination (through imbibition process), movement, reproduction, respiration, nutrition, excretion, irritability, metabolism, adaptation, death, etc), health of man (water is the foundation of a healthy body; it has healing abilities through hydration) and human body (hydrates the body cells such as the brain cells). Hydration affects human brain and mental health, energy level, human blood pressure (unexpected blood pressure drug) and mood (more intake of water improves mood (better mood), detoxifies the body system, reduces tension, depression and confusion) and weight loss (increase water intake leads to weight loss). Water supports plants and animals, enables transport nutrients (such as glucose and amino acids in blood, and sucrose in phloem), removal of excretory products (e.g. ammonia, urea), secretion of substances (e.g. hormones, digestive juices) and regulates temperature due to its high specific heat capacity. Water produced as a metabolic product of respiration is essential for living organisms, especially those living in dry habitats. It is the final electron acceptor in the electron transport chain. In addition, it affects climate and weather (thus coastal areas experience more rainfall than upland areas), sound waves and environment. It is the habitat for myriads of organisms. Its properties such as universal solvent (solvent for many ionic and polar substances, metabolic reactions [catabolic such as digestion, hydrolysis (proteins to amino acids), glycolysis (breakdown of glucose to pyruvic acid under aerobic conditions or lactate under anaerobic conditions), and anabolic such as plant photosynthesis and its rate, bone mineralization], insulator, high specific heat capacity, high latent heat of vaporization, surface tension, density and freezing, transparency and colloid formation explain its indispensable nature. Water is the culture environment for fish.

It is very important to note that humans can live without food for over 60 days but cannot do without water for more than a few days (3 days). Aestivating, hibernating and diapausing organisms need aqueous medium for survival. Therefore water is indispensable for virtually all living organisms on our planet earth. This indispensability of water to all of us irrespective of status, age, attainments, etc prompted the topic of this inaugural lecture.

Fish are an important renewable natural resource to meet man's and animal's needs of food (essential nutrients and micronutrients) (Ugwumba *et al*., 1995; **Davies** *et al*., 2006a; **Davies** *et al*., 2008b; **Davies** *et al*., 2008c; **Davies** and Otene, 2009; **Davies** and Ezenwa, 2010; Ikenweiwe *et al*., 2011), oil, meal, medicine, recreation, tourism, sporting, adornment, decoration, animal feeds, bio-energy (**Davies** and Davies, 2012; **Davies** *et al*., 2013a; **Davies and Davies, 2013; Davies and Davies, 2014; Davies and Davies, 2017**) and other fish products (cakes, biscuits, soups). Others are primary oxygen source (**Davies** *et al*. 2006b; **Davies** *et al*. 2008a; **Davies** *et al*. 2009a; **Davies** *et al*. 2009b; **Davies** and Ugwumba, 2013a; **Davies** and Nwose, 2018a), bio-monitoring (Ekeke *et al*., 2008), bio-indicator (**Davies** *et al*., 2006a; **Davies** *et al*., 2006c; **Davies** *et al*., 2007; **Davies** *et al*., 2008a; **Davies** *et al*., 2008b; **Davies**, 2009; Abolude *et al*., 2009; **Davies** *et al*., 2018a) and bioremediation of pollution, nutrient recycling (**Davies** *et al*., 2008a; **Davies**, 2009a; **Davies** *et al*., 2009a; **Davies** *et al*., 2009b; **Davies and Ugwumba, 2013a; Davies** *et al*., 2015), organic buffer (**Davies** and Ansa, 2014; **Davies** and Jaja, 2014b; **Davies** and Ogidiaka, 2015; **Davies *et al*., 2015; Davies** and Ogidiaka, 2017; **Davies** and London, 2018), eutrophication control (**Davies *et al*., 2015**), food security (FAO, 2016), employment and livelihood (**Davies**, 2004, FAO, 2018), source of raw materials for industries (Davies and **Davies**, 2012; **Davies** and Ansa, 2014; **Davies**

THE INDISPENSABLE CREATION IN OUR PLANET

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and Ogidiaka, 2015; **Davies *et al.*, 2015; Davies** and Ogidiaka, 2017), foreign exchange (FAO, 2018), crafts and arts.

Water continuously moves above, on, and below the earth surface in a cycle called hydrologic or water cycle (Fig. 1). Hydrologic cycle can be described as the physical change of water from solid to liquid to gas in a cycle. There are four main steps namely evaporation (the process where the heated water turns into a gas called water vapor), condensation (the process where the water vapor turns into a liquid and forms clouds), precipitation (the process where the water from the clouds returns to the ground or sea via rain, snow, or sleet) and water movement (the process where water that falls on land (runoff) usually flows downhill into surface waters). The cycle performs the following functions: **affects climate and other biogeochemical cycling,** distributes water on the earth, purify water, supports plant growth, sustains aquatic ecosystem, controls the ecological function of any aquatic system, facilitates agriculture and promotes human civilization**.**

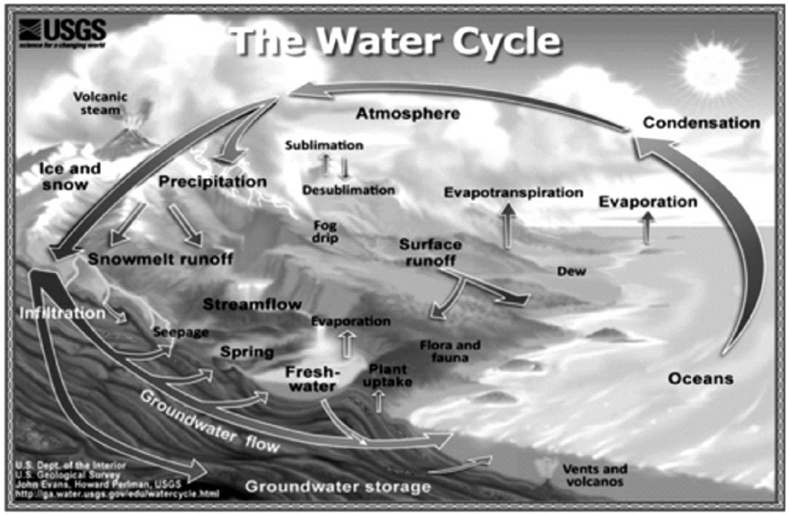

Fig. 1: Hydrologic cycle

Source: http://ga.water.usgs.gov/edu/watercycle.html

2.4 Man, steward of indispensable creation on earth

Man is the steward of all creation. It is the responsibility of man to take care of the waters and aquatic organisms as commanded by God in Genesis Chapter 1 verse 28b "And have dominion over the fish of the sea and over the fowl of the air, and over every living thing that moveth upon earth". Dominion in this context means stewardship, caretaking, management, auditing, caring for or improving on the sustainability of God's creation.

3.0 AQUATIC ENVIRONMENTS

The liquid water bodies referred to as **aquatic environments** are the habitats for aquatic organisms (plants and animals) as recorded in Genesis Chapter 1verse 20[a] "Then God said, "Let the waters abound with an abundance of living creatures". The aquatic environments are also known as **SEAS** according to Genesis Chapter 1 verse 10[a] "And God called the dry land Earth; and the gathering together of the waters called the **Seas**" but they are further classified as shown below. However, **aquatic environment** can be defined as interacting system of resources such as **water, sediments and biota (life)**. The aquatic environments are divided into three main types based on their salt content (salinity) by scientists as freshwater (0.05 ‰; range 0.01 – 0.05 ‰); brackish water (<30 ‰; range 0.05 – 29.9 ‰) and marine water (>30 ‰; range 30 – 35 ‰). Aquatic environment was also classified based on their total dissolved solids concentration by Atekwana *et al*. (2004) as follows: freshwater –less than 500 mg/L or <500 ppm (part per million); brackish water= 500-30,000 mg/L or 500-30,000 ppm; saline water- 30,000 - 40,000 mg/L or 30,000 - 40,000 ppm and hypersaline –greater than 40,000 mg/L or >40,000 ppm.

These environments are further classified as inland waters and marginal/border/frontier/territorial waters based on their demography/location. Inland water is any of the waters such as rivers,

families of Bubu, Dafe and Davies. My modest background and challenges of life could not hold me back. My dream, my late father's dream came to past by God's Infinite Mercy, Compassion, Grace and Faithfulness. Therefore, to the Master of the Universe, the Lord of Lords, the Rose of Sharon and the Lily of the Valley, let us sing………

TO GOD BE THE GLORY

To God be the Glory! Great things He hath done
So loved He the world that He gave us His son,
Who yielded His life atonement for sin,
And opened the life gate that all may go in

Chorus: Praise the Lord! Praise the Lord!
Let the earth hear His voice!
Praise the Lord! Praise the Lord!
Let the earth rejoice
Oh come to the father, through Jesus the son
And give Him the Glory, Great things He hath done

Oh perfect redemption, the purchase of blood
To every believer the promise of God
The vilest offender who truly believes
That moment from Jesus a pardon receives

Chorus……………………………………………

10.0 EPILOGUE

Romans Chapter 9 verses 15-16 "*For he saith to Moses, I will have mercy on whom I will have mercy, and I will have compassion on whom I will have compassion. So then it is not of him that willest, nor of him that runneth, but of God that showest mercy*". Reflecting on the past till date, it has been God's mercy that I have not been consumed and his unending mercy that I have been made a Professor of Hydrobiology and Fisheries though I lost the original effective date of 1st October, 2014 due to the 34-month principle ASUU strike I joined. All my publications that qualified me as a professor ended with April 2014 publications. I believe the effective date of my promotion will be restored one day. I remember my unconventional school (Jelesimi in Yoruba language) teacher, an elderly man who taught me to write on black slate with white chalk. You laid the good solid foundation of my education and academic career. May your soul rest in perfect peace! God bless your generations. My committed teachers at Abadina Primary School, University of Ibadan, even though I have forgotten your names but you laid the correct blocks on the solid foundation. You impacted on me the right and fruitful knowledge as well as core values of life. All my teachers (Nigerians and Foreigners) at Onireke High School, a School established by Late Chief Bola Ige, the then Civilian Governor of Oyo State during Alhaji Shehu Shagari's Administration. Notable among them was my Mathematics Teacher at Class 2 who taught me to rejoice with those that do better than me in academics. A short well spoken speech that has become my watchword and also it has contributed to my success story. You built on the laid sound foundation. All my university teachers at the Department of Zoology, University of Ibadan that laid the right blocks on the existing solid foundation to complete the project, Prof. Onome Augustina Bubu (Nee Bubu). Where are they now? Some may be living or dead! I am a product of these lowly faithful government teachers and my humble parents who has become the first Professor in Aragba-Okpe Town, Okpe Local Government Area of Delta State and

lakes, canals, pools, ponds, watercourses inlets, and bays within the territory of a country while marginal water is open seas bordering another country subject to various sovereign rights of the bordering country.

3.1 Types of aquatic environments

In this lecture, we will look at aquatic environments grouped based on salinity into three water bodies.

3.1.1 Freshwater environment

The freshwater environment is a source of drinkable water and equally used for agriculture purposes. It constitutes 2.5 % of water on earth. It provides about 3% of its net primary production and contains 41% of the world's known fish species. The freshwater environment is divided into the followings:

Lentic or still system: It is the slow moving water such as pools, ponds and lakes.

Lotic or running system: It is the faster moving water namely streams and rivers.

Underground system: The underground freshwater system is below the surface of the earth. The source of freshwater is precipitation from the atmosphere in the form of mist, rain and snow.

Wetlands: The wetlands are areas where the soil is saturated or inundated for at least part of the time.

The lentic, lotic and wetland freshwater systems are referred to as surface waters.

3.1.2 Brackish environment

The brackish water environment is described as an environment of fluctuating salinity that favours some important species. It contains 0.5% of the water on earth. This environment includes estuaries, swamps, lagoons and deltas of rivers which are under the influence of tidal regime.

3.1.3 Marine environment

The marine environment is an environment of high salt content (average 35 ‰) and the largest of all the aquatic habitats. The fresh and brackish waters empty into the marine environment. Examples are sea and ocean. The marine environment contains approximately 97% of the water of the planet. It produces 32% of the world's net primary products. Over 90% of the planet's living and non-living resources are found within a few hundred kilometers of the coast (Amosu and Babalola, 2010).

3.2 Properties of aquatic environments

The aquatic environments are made up of abiotic (non-living such as physical and chemical features) and biotic (life/flora and fauna/ communities of organisms) properties. These are dynamic in nature.

3.2.1 Physical properties

They are temperature, turbidity, transparency, **density, tides, depth, velocity, pressure amongst others.**

3.2.2 Chemical properties

The chemical properties are pH, dissolved oxygen, salinity, electrical conductivity, biological oxygen demand/ biochemical oxygen demand, chemical oxygen demand, total suspended solids, total organic carbon, alkalinity, chloride, calcium, magnesium, hardness, nutrients (ammonia, nitrate, nitrite, nitrogen, phosphate, sulphate), heavy metals (iron, zinc, copper, cadmium, chromium) and **polycyclic aromatic hydrocarbons, to mention but a few.**

Opusunju, Boma Dambo, Patience Obinna-Echem, S.A. Ngah, Kenneth Gagde, Clifford Nwanyanwu, Esezi I. Obilor, A. U. Nnodim, Alolote Amadi, E. A. Hart, Mrs. J.N. Igwela, Mr. Monday Ndor, Mr. G. O. Echonwere, Mrs. Edith N. Enyi, Engr. Dune, TP. Gift Nkwo, Mrs. M. Izzi and Mrs. Margaret Harry for their good team players' spirit and cooperation. I have really learnt and gained skills from you all. Remain blessed. To all the Industrial Attachment Students at Roone Fish Farm, Abuloma, Beauty, Tamuno Ajubo Okpaku, Inspector George, Hassan Abu, Peremebowei Beldin Kpikpi, Egolukumor Pius Paper-Felzy, Perepuide Felix Egoli and Priscillia, I am grateful for your contributions to my research works. To all that have contributed to my success story within and outside the Rivers State University that I did not mention your names, I say a big thank you and God bless.

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3.2.3 Biological properties (flora and fauna)

The biological properties are all the indispensable plants (flora) and animals (fauna) in the dynamic waters that will be discussed later. The flora are phytoplankton (primitive, unicellular passively drifted plants/microalgae), periphyton (attached, unicellular algae), seaweeds (sessile, macroalgae or plant-like organisms) and macrophytes (larger aquatic plants). The fauna are divided into the invertebrates and vertebrates. The invertebrates are zooplankton (primitive passively drifted animals though some are vertebrates such as larvae of finfishes), coelenterates (sea anemone, jelly fish), echinoderms (sea star/star fish, sea urchins, sea cucumber), mollusks (periwinkles, oysters, bloody cockles, clams, rock snails) and crustaceans (shrimps, prawns, crabs) while the vertebrates are Agnatha, jawless fish (sea lamprey), Gnathostomata, jaw fishes/finfishes (Chondrichthyes [cartilaginous fishes such as sharks] and Osteichthyes [bony fishes such as catfishes, tilapias, carps, etc]), amphibians (frogs), reptiles (sea turtles, alligators, crocodiles, monitors), aves (birds) (ducks) and mammals (whales, dolphins, etc). Representative organisms of these groups of plants and animals are shown in Plates 1a to 1p.

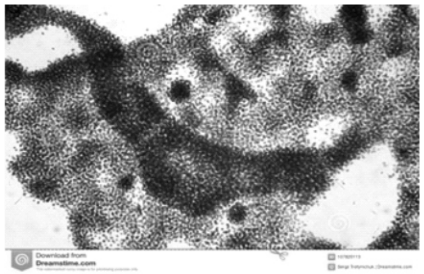

Plate 1a: *Microcystis sp (phytoplankton)*

Plate 1b: *Euglena sp (periphyton)*

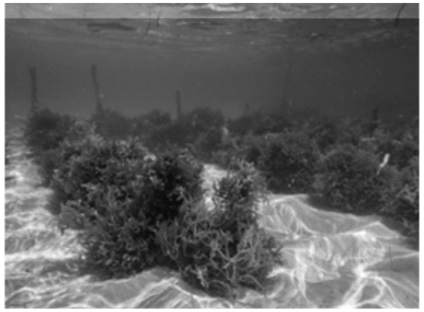

Plate 1c: Seaweed

Plate 1d: Water lily (Macrophyte)

Sources: web and personal

Plate 1e: Sea Urchin larva (zooplankton)

Plate 1f: Sea Anemone (Coelenterate)

Plate 1g: Sea Star (Echinoderm)

Plate 1h: Clams (Molluscs)

Plate 1i: Shrimps (Crustaceans)

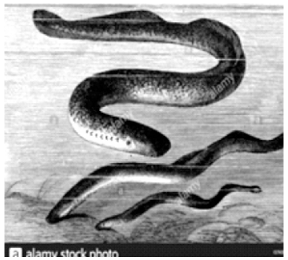

Plate 1j: Sea Lamprey (Agnatha)

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Plate 1k: Shark (Chondrichthyes)

Plate 1l: Catfish (Osteichthyes)

Plate 1m: Green and brown frog (Amphibian)

Plate 1n: Sea turtle (Reptile)

Plate 1o: Duck (Aves)

Plate1p: Dolphins (Mammals)

Sources: web and personal

3.2.3.1 Seaweeds

Seaweeds are marine macroalgae or plant-like organisms that generally live attached to rock or other hard substances in intertidal and subtidal areas. The major classes of seaweeds are: *Rhodophyceae* (red seaweed), *Phaeophyceae* (brown seaweed) and *Chlorophyceae* (green seaweed). They serve the following functions:

- Seaweeds provide food and shelter for fish and crustaceans in the aquatic environment.
- Seaweeds can be used to create waste water treatment for excessive nutrient removal (Nitrogen and phosphorus).

- Seaweeds are excellent source of vitamins, protein and minerals for human health growth.
- Seaweed cultivation represents close to half of the biomass of the world marine culture production,

3.2.3.2 Benthic Fauna

Benthos is a community of organisms that live on, or in, the bottom of a water body. The benthic community is divided into the phytobenthos (bacteria, plants) and zoobenthos (animals) and from the different levels of the food web. Benthic animals are usually grouped by size: microbenthos <0.063 mm, meiobenthos 0.063–1.0 (or 0.5) mm, macrobenthos >1.0 (or 0.5) mm and megabenthos > 10.0 mm (***Davide and Marco, 2010)***. The commonest benthic animals (benthic invertebrates) are worms such as polychaetes and oligochaetes, molluscs such as bivalves and gastropods, and crustaceans such as amphipods and decapods. Benthic fauna are usually used as biological indicators as they can provide information on environmental conditions either due to the sensitivity of single species (indicator species) or because of some general features that make them integrate environmental signals over a long period of time (***Davide and Marco, 2010)***.

3.3 Importance of waters

In the Bible (spiritual uses), water is used for the followings:

3.3.1 Cleansing

Water is important for cleansing (Exodus 29:4; Hebrews 10:22). Exodus 29:4 (AKJV): And Aaron and his sons thou shalt bring unto the door of the tabernacle of the congregation, and shalt wash them with water.; Hebrews 10:22 (AKJV): Let us draw near with a true heart in full assurance of faith, having

THE INDISPENSABLE CREATION IN OUR PLANET

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our hearts sprinkled from an evil conscience, and our bodies washed with pure water.

3.3.2 Symbolic of God's blessing and spiritual refreshment

Water is symbolic of God's blessing and spiritual refreshment and is used many times in the Bible (Isaiah 35:6-7). Isaiah 35:6-7: Then shall the lame man leap as an hart, and the tongue of the dumb sing: for in the wilderness shall **waters** break out, and streams in the desert. And the parched ground shall become a pool, and the thirsty land springs of water: in the habitation of dragons, where each lay, shall be grass with reeds and rushes.

3.3.3 Danger and Death

Water is often associated with **danger and death (**Gen. 6:17; Psalm 124:4-5). Gen. 6:17: And, behold, I, even I, do bring a flood of waters upon the earth, to destroy all flesh, wherein is the breadth of life, from under heaven; and everything that is in the earth shall die. Psalm 124:4-5: The waters had overwhelmed us, the stream had gone over our soul. Then the proud waters had gone over our soul.

Physically, water performs the followings functions:

3.3.4 Provide habitats for wildlife

The aquatic environments accommodate wide arrays of animals (invertebrates and vertebrates).

3.3.5 Fishing

Fishing is carried out in the aquatic environments.

3.3.6 Domestic/Residential

Water is used for residential purposes namely: drinking, bathing, cooking, cleaning utensils, cleaning the house, laundry, personal hygiene, lawn care, home-gardening, car washing, sanitation and landscaping among others.

3.3.7 Recycle nutrients

Nutrient recycling takes place in the aquatic environment by aquatic plants (phytoplankton, periphyton, seaweed and macrophytes).

3.3.8 Human recreation

Swimming and other recreation activities take place in the aquatic environments.

3.3.9 Commercial and Industrial Uses

Water is used for commercial and industrial purposes; processing products, cooling, washing, etc.

3.3.10 Hydropower or hydroelectricity

Water is used for hydroelectric facilities; flowing water is used to turn turbines that produce hydroelectricity.

3.3.11 Agriculture (irrigation, crop farming, livestock farming, capture and culture fisheries, aquaculture, aquaponics)

Water is utilized in agriculture for livestock farming, aquaculture (Davies and Ansa, 2010) and irrigation for crop farming. Surely, we cannot do without water.

3.3.12 Navigation

Water is used for navigation which is transport on watercourses either for intrastate, interstate or foreign commerce (International Commerce/trade) (Davies, 2008). Agricultural and other commercial goods are moved on water on a large scale. **Massive ships** such as service vessels, industrial ships, passenger carriers and cargo carriers (an example is **ocean tanker/tank ship)**, **pleasure vessels**, **house boats, lifeboats** to mention a few tranverse the waters of the world. **Service vessels** are used to tow massive drilling rigs for the petroleum industries and towing of disabled ships. **Industrial ships**

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8.0 TWO OF A KIND

Poem BY

PROF. ONOME DAVIES AND PROF. OLUFEMI ADESOPE

God's creation
In all the nation
Like a vision
Two of a kind
In all of mankind
How indispensable
God dispensed his creation

Two of a kind
In different states of matter
How important is the water
How important is the fish
Two of a kind
One in a solid state
The other in a liquid state
From the Perfect and Greatest Chemist

One was commanded
To bring forth another
And so it was
Two of a kind
You are no twins
But two that be agree

Can two walk together
Except they be agree?
I have see two of a kind
That be agree

God's own creation
And man's inevitable companion
Food and drink to man
Two of a kind
That are indispensable to mankind
Dynamic creation of the earth
Adlib is your watery presence
And so the solid presence
Under the unending body of matter
That covers the earth
Two of a kind
Majestic creation from the Almighty
Two indispensable gifts to mankind
Fish and water
Satisfying hunger and thirst
Two of a kind
Indispensable twin from Mother Nature

provide industrial process at sea such as a fishing-fleet mother ship that processes fish into fillets, canned fish, or fish meal. Some industrial ships serve as floating oil drilling or production rigs. Some hazardous industrial wastes are incinerated far at sea on ships fitted with the appropriate incerators and supporting ships. **Passenger carriers** are merchant ships that carry passengers (for example,cruise ship, MS Freedom of the sea ship (Plate 2a) carries up to 3,634 passengers) on the sea. **Cargo carriers/ships** are freighter ships namely tank ships (Plate 2b), container ships (Plate 2c), general cargo vessels, dry bulk carriers (Plate 2d), multi-purpose vessels and reefer or refrigerated ships (Plate 2e).These ships carry cargo, goods and materials from one port to another on seas and oceans. **Ocean tankers** are ship designed for the bulk transport of oil or its products. There are two types: **crude and product tankers**. **Crude tanks** are big tank ships that move large quantities of unrefined crude oil from its point of extraction to refineries, for example, oil wells in Nigeria to refineries on the coast of the United States while **product tankers** are smaller tank ships that transport refined products from refineries to points close to consuming markets. For example, transport of gasoline from refineries in Europe to consumer markets in Nigeria and other West African nations. **Pleasure vessels** are large motorboats such as ski boat, pontoon boats and sailboats (Plate 2f). They have cabin, conveniences and other accessories used in recreational boating. **House boats are used for vacationing or long-term residence. Lifeboats** serve as rescue and safety boats.

Plate 2a: Cruise ship, MS Freedom of the sea

Source: https://en.wikipedia.org/wiki/MS Freedom of the Seas

Plate 2b: Tank ship

Source: https://en.wikipedia.org/wiki/Oil_tanker

Plate 2c: Container ship

Source: https://en.wikipedia.org/wiki/Bulk_carrier

Plate 2d: Bulk carrier

Source: https://en.wikipedia.org/wiki/Cargo_ship

Source: https://en.wikipedia.org/wiki/Reefer_ship

Plate 2f: Pleasure vessel

Source: https://en.wikipedia.org/wiki/file:motorboat_at_kankaria_lake.JPG

Controlled anthropogenic activities such as fishing, dredging, oil and gas exploration and production (crude oil refining) should be adopted.

Closed fishing season and approved fishing gear with the correct mesh size should be adopted. Government should establish aquaculture for the fisher folks to avoid over-fishing of the fish stock of open waters and culture-based fisheries for restocking of the degraded aquatic environment (to restore the depleted fishstock).

Effective extension works and research linkages.

Right to "Clean Water Law" in the Water Law of our constitution should be enacted, implemented and enforced.

The government (Federal, State and Local), communities and individuals should be involved to keep the health of the aquatic environments. All these must be observed for the good health of the dynamic aquatic environments and production of healthy food fish and other fish products.

Kindly join me to be good stewards of God (Genesis 1:28), to preserve, conserve, protect, manage and culture the indispensable creation of our planet (dynamic waters and fish) by adopting the above suggestions.

7.0 RECOMMENDATIONS

Mr. Vice-Chancellor, Sir, the followings recommendations are made from my contributions to knowledge on indispensable dynamic inland waters in relation to their physical, chemical and biological features:

Considering the abundance of microalgae in our inland waters, useful ones such as *Spirulina sp* should be cultured for human health food and medicines. From our University Anthem "Fruitful Science and Tech We Grow", I therefore advocate for multi-disciplinary (Fisheries & Aquatic Environment, Animal & Environmental Biology, Plant Science & Biotechnology, Microbiology, Biochemistry and Chemistry and Pharmacology) research to increase the glycolipids, polysaccharides and other pharmaceuticals (anti-viral, antibiotics, anti-cancer, etc) contents of blue-green algae during culture for drugs against AIDS virus, bacterial infections, cancer and other diseases as well as culture of phytoplankton and macrophytes as sources of biofuel (renewable energy), bio-remediation, bio-indicators and bio-monitors of pollutants. Policy brief should be written from research to assist policy makers to proffer good policy.

Concentration of phosphate in domestic and industrial detergents should be reduced to the international level to avoid eutrophication and harmful algae blooms.

Wastes from various residential and industrial areas should be recycled into useful products such as organic fertilizer, particle board, organic buffers, biofuel, etc.

Mass enlightenment programme should be organized on poor wastes management from domestic and industrial areas.

Effective fisheries legislation should be enforced.

Concerted environmental surveillance on the aquatic environments to avert increases in nutrient status and organic loads should be done.

Regular monitoring and evaluation of the open waters should be conducted to ascertain their biological integrity (health).

3.3.13 Dredging

Dredging is underwater excavation of the bottom of the water bodies. It is carried to out to reclaim land, ease navigation and for providing sand. Sand is dredged or excavated from the aquatic environment for buildings and constructions (such as artificial islands in China) as well as for easy navigation (Davies, 2008).

3.3.9 Ecotourism especially in coastal areas

The aquatic environments serve as ecotourism centers

3.3.10 Purification of water

Purification of water takes place in the aquatic environments.

3.3.9 Environmental

Water is required for environmental purposes such as open water fisheries (capture and culture fisheries), temperature modulation and wetlands.

3.4 What is dynamic aquatic environment?

Dynamic aquatic environment is an environment **(natural and man-made)** with **continuous changing or developing physical, chemical and biological characteristics of the water and sediments (Davies** *et al*., 2008c; **Davies** and Abowei, 2009; **Davies** and Tawari, 2010; **Davies** and Ansa, 2010; **Davies** and Kwen, 2012; Kwen *et al*., 2012; **Davies**, 2013; **Davies** and Tawari, 2013; Abolude *et al*., 2013; **Davies**, 2014)**. These continuous changes involve vigorous activities caused by natural and anthropogenic factors.**

Physical alterations include changes in water temperature, water depth, water flow, tide, turbidity, transparency (light availability), velocity and density to mention but a few.

Chemical changes include alterations in pH, alkalinity, salinity, dissolved oxygen, dissolved carbon dioxide, electrical conductivity, nutrients (nitrate, phosphate, ammonia, sulphate), total dissolved solids, total organic carbon, total organic matter, toxins, oxygen consuming materials, nitrification **and d**enitrification, etc.

Biological alterations caused by anthropogenic factors include harmful algae blooms (HABs), over-fishing of commercial species, low species composition, abundance and diversity, introduction of exotic species, migrant species, etc.

The physico-chemical parameters of the aquatic environment (pH, temperature, dissolved oxygen, biological oxygen demand, total alkalinity, nitrate, phosphate, sulphate, conductivity, salinity, transparency, turbidity, chloride, hardness, calcium, total dissolved solids, etc.) influence the biological population and vice versa.

These abiotic and biotic parameters are used to detect any changes or perturbation in the aquatic environment (**Davies** *et al*., 2008a; **Davies** *et al*., 2008b; **Davies** *et al*., 2008c; **Davies** *et al*., 2009a; **Davies**, 2014). Aquatic organisms in their ecosystem which encompassed the physical and chemical components are inseparable, inter-related, interacting and overlapping with one another. The physical, chemical and biological properties are affected by climate, season, weather, location, month and year.

An aquatic environment is said to be **stressed** or **perturbed** or **disturbed** as a result of continuous changes or alterations in the physical, chemical and biological features of the environment. Stress degrades and may destroy the health of an aquatic ecosystem when it goes beyond the carrying capacity or threshold of the ecosystem. It is basically caused by **man** (**anthropogenic factor**). Examples of stress include discharge of untreated domestic and industrial effluents, water pollution, over-fishing, dredging, invasive species, damming, levee construction, logging of swamps to mention but a few.

However, Mr. Vice-Chancellor, Sir, the physical, chemical and biological features of the inland waters are indicators of the productivity, fisheries production, health, stress and aquatic pollution. Some physico-chemical (temperature, transparency, pH, EC, DO, BOD, COD, TDS, TSS and alkalinity) are indicators of the health, nutrient enrichment (eutrophication), productivity and organic pollution of the inland waters. Nutrients especially phosphate and ammonia have been threat to the biological integrity of the studied aquatic ecosystems, indicating organic pollution. The studies on heavy metals (Cu, Fe, Zn, Pb, Cr and Cd) documented that these metals bioaccumulate, bioconcentrate and biomagnifiy in water and sediments as well as in periwinkles and crabs. Some of these metals were found in these waters, sediments and biota above the permissible limits for natural open waters, sediments and fish; making the fish unfit for human consumption. PAHs were observed in the studied inland aquatic environment; also making the fish from this water body unfit for human consumption. There is low finfish species composition, diversity and abundance due to and aquatic pollution and uncontrolled anthropogenic activities such as indiscriminate fishing and dredging.

Mr. Vice-Chancellor, Sir, shells (wastes) of shellfishes such as oysters, bloody cockles, rock snails and periwinkles as well as macrophytes such as water hyacinth are utilized as organic buffers for acidic borehole for fish production through aquaculture. These are ways to turn wastes to wealth (resources). Phytoplankton growth can be induced in ponds/tanks with micro nutrient fertilizer such as agrolyser for production of herbivorous fishes such as tilapia and Heterotis niloticus.

Finally, Mr. Vice-Chancellor, Sir, phytoplankton and macrophytes (water hyacinth, water lily, water lettuce) are used for production of briquettes (biocharcoal, biofuel), source of renewable energy which are environment friendly and affordable and also, a way of converting wastes to wealth.

6.0 CONCLUSIONS

Mr. Vice-Chancellor, Sir, my findings have revealed that the dynamic waters (natural and man-made) and fish are indispensable. Water is the most abundant component of any living organism for its survival and well being. Mr. Vice-Chancellor, Sir, fish (all living aquatic organisms) are an important renewable natural resource to meet man's and animal's needs of food (essential nutrients and micronutrients), oil, fishmeal, medicine, recreation, tourism, sporting, adornment, decoration, animal feeds, bio-energy and other fish products (cakes, biscuits, soups). Others are primary oxygen source), bio-monitoring), bio-indicator and bioremediation of pollution, nutrient recycling, organic buffer, eutrophication control, food security, employment, source of raw materials for industries, foreign exchange, crafts and arts. The properties of these dynamic waters in terms of the physical, chemical and biological have shown that there are continous changing and developing of these environments. Also, there are various vigorous activities (death of organisms, decomposition, denitrification, nitrification, erosion, oil and gas exploration and production, sand dredging, indiscriminate waste disposal, navigation, fishing, laundry, bathing, washing, hydroelectricity, agriculture, etc) within these environments caused by natural and anthropogenic factors. Nigeria is richly blessed with many water resources (inland freshwater and brackish ecosystems) and fish.

Mr. Vice-Chancellor, Sir, phytoplankton are primary producers, producers of the biomass, primary food source for man, fish and other animals, source of various products (oil, chemicals, pharmaceuticals and polysaccharides), nutrient recyclers, organic buffer for low pH, euthrophication controller, primary oxygen source (oxygenator), bioremediator, bioindicators and biomonitors. The blue-green algae, especially *Spirulina sp* are a source of health and medicinal products. Studies on phytoplankton of some inland waters revealed that they are highly productive for fisheries production but they are under stress and organically polluted. Also, some of the studies unveiled HABs genera in some inland waters; warning against their blooms and effects on man, fish, other animals, ecology and socio-economics.

3.5 Causes of dynamic aquatic environments

There are two main causes of dynamic aquatic environments; these are the natural and anthropogenic (human/man) causes.

3.5.1 Natural causes

These are induced by nature such as substratum (organic and inorganic materials that make up the bed or bottom of an aquatic environment), death of organisms (natural mortality), decomposition, denitrification, nitrification, season, weather, erosion due to rainfall and runoffs, sedimentation, earthquakes leading to tsunamis to mention but a few.

3.5.2 Anthropogenic causes

These are induced by man such as fishing, dredging, navigation, damming, oil and gas exploration and production, agriculture, culture-based fisheries, industries, deforestation, habitat destruction, over-exploitation **of** resources, influence **of** climate change, urbanization, pollution and others. These factors which are within the natural control of humans can be consciously regulated, monitored and conserved for the sustainable re-invigoration of the aquatic ecosystems and delivery of their functions.

3.5.3 Aquatic Pollution

Aquatic pollution can be defined as the release of harmful materials (organic and inorganic wastes) typically generated through human activities including industrial (oil and gas exploration and production, refining of crude oil, dredging, thermal, radioactive, etc), domestic and agricultural wastes, into the receiving water environment. It can be described as the introduction or addition of organic and inorganic materials to the aquatic environments to concentrations exceeding the permissible limits tolerable by nature. There are two types of pollution: point-source and diffuse or non-point pollution which leads degradation of water quality and further affects the ecological integrity of the aquatic environment, for example, deplete the available dissolved oxygen required by aquatic organisms.

Point-source pollution is the discharge of pollutants into the ecosystem through a single source such as wastewater, sewage, industrial and heat discharges from a slaughter house, residents and industries. **Diffuse- or non-point source pollution** is the discharge of pollutants into the ecosystem through more than one source usually as a result of agricultural and forestry activities as well as storm drainage and mobile vehicular discharge via atmospheric pollution (acid rain). It can also occur where there is small-scale mining over a large area. It includes pollutants which enter the aquatic environment from soil or groundwater system and from the atmosphere via rainfainfall.

Aquatic ecosystems undergo constant changes and adaptations, and can withstand stress based on their unique physical, chemical and biological properties. Ecosystems may become unbalanced because of various anthropogenic factors. Each species of animal and plant has optimal ranges for physical and chemical requirements, beyond these ranges, the environment is regarded as being stressed, disturbed, perturbed or polluted. Outside these ranges, organisms faced increasing stress and those intolerable to the posed stress may eventually die. Even when all physical and chemical characteristics of the environment fall within tolerable limits, composition, diversity, abundance and distribution of species can be influenced by various combinations of these stress factors. This may logically explain the ecological variety that makes each aquatic environment very peculiar. The interpretation of these factors requires an integrated approach

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Renewable Energy

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and a sound understanding of the interdependent nature of biological systems and abiotic influences over time and space.

3.6 Specialized disciplines associated with aquatic study

Below are types of studies on the aquatic environments.

3.6.1 Hydrobiology

***Hydro* means water, *bio* means life and *logy* means study. Therefore, the literary meaning of Hydrobiology is water biology, that is, the study of life (including physical structure, chemical composition, function, development and evolution) in water (freshwater, brackish and marine) or study of aquatic organisms. However, it has a deeper definition as the study of water populations, their interrelations with habitats and their significant for the transformation of energy and matter, and the biological productivity of the ocean, seas, and inland waters are also integral to hydrobiology. Consequently, hydrobiological methods are adopted to evaluate the extent of water pollution through the presence of certain indicator organisms (also known as biological analysis of water) (Davies, 2008). Furthermore, hydrobiology studies the role of aquatic organisms as agents of self-purification of aquatic environments. Quantitative methods for investigating natural communities of aquatic organisms in order to determine the number (density) of individuals of different species and their biomass have received very broad attention in hydrobiology. There are many specialized hydrobiological equipment such as plankton nets (Plate 3a), plankton samplers (Plate 3b-3f) and bottom grabs (Plate 3g) of various designs used for this purpose. Hydrobiology covers limnology and oceanography. There are various areas of studies in h**ydrobiology namely reproduction, nutrition, growth, excretion, movement, respiration, taxonomy, economic biology, industrial biology, morphology, physiology, histology amongst others.

Plate 3a: Plankton net (tow)

Plate 3b: Wisconsin Plankton sampler 80μm

Plate 3c: Net Repl S-P Trap

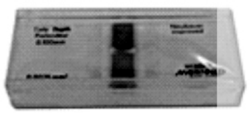

Plate 3d: Hemacytometer

Plate 3e: Vials

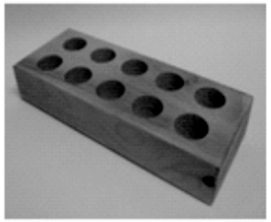

Plate 3f: Vial Rack

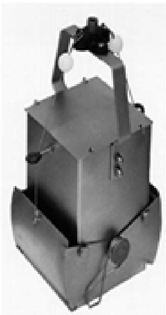

Plate 3g: Ekman Grab

Sources: www.alamy.com/stock-photo/plankton-net.html ; https://shop.sciencefirst.com/wildco/531-plankton-samplers-and-processing; https://www.amazon.com/Ekman-Grab-Tall-6x6x9-grab/dp/B0096E7GY4

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Fish production through Aquaculture and Fish Processing

- Gabriel, U.U., Inko-Tariah, M.B., Allison, M.E. and **Davies, O.A**. (2000). Growth and survival of *Heterobranchus bidorsalis* fingerlings fed varying dietary protein and energy ratio. *Journal of Agriculture, Biotechnology and Environment*, 2 (1/2): 35-41.
- Inko-Tariah, M.B., Gabriel, U.U., Allison, M.E. and **Davies, O.A**. (2001). Comparative studies on the yield of *Oreochromis aureus* in a polyculture system. *Journal of Agriculture, Biotechnology and Environment*, 4 (1/2): 15-20.
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Hydrobiology studies are very challenging especially on open natural waters (**Davies** *et al*., 2008a; **Davies**, 2009; Ikenweiwe *et al*., 2011; Otene and **Davies**; 2013; **Davies *et al*., 2015**; **Davies** and Nwose, 2018a). The study of life in water cuts across the three main types of aquatic environments and it cannot be done in isolation of the physical and chemical properties of water.

3.6.2 Limnology

Limnology is the study of all inland aquatic ecosystems (freshwater or saline, natural or manmade waters such as lakes, reservoirs, ponds, rivers, groundwater, swamps, wetlands, marsh, etc.) including its biological, physical, chemical, geological, ecological and hydrological components (**Davies** *et al*., 2008a; **Davies** and Ansa, 2010; **Davies**, 2013; **Davies**, 2014; **Davies** *et al*., 2018b; **Davies** and Abowei, 2009; **Davies** and Tawari, 2010; **Davies** and Tawari, 2013).

3.6.3 Oceanography/Oceanology

Oceanography or oceanology is the study of the physical, chemical and biological aspects of the ocean. It has four branches namely, **biological oceanography or marine biology** (investigates the ecology of marine organisms); **chemical oceanography and ocean chemistry** (are the study of the chemistry of the ocean); **geological oceanography, or marine geology** (is the study of the geology of the ocean floor including plate tectonics plate tectonics) and **paleoceanography** and **physical oceanography**, or **marine physics** (studies the ocean's physical attributes including temperature-salinity structure, mixing, surface waves, internal waves, surface tides, internal tides and currents).

3.6.4 Fisheries

There is need to define these terms: fish, fishing, fisheries (capture and culture) and aquaculture for better understanding and clarity of this lecture.

3.6.4.1 Fish

Fish are an important renewable natural resource to meet man's needs for food (nutrients and micronutrients), oil, medicine, recreation and other fish products. Fish is the best source of animal protein in the world. Additionally, it is one of the most important natural renewable resources for economic benefits of mankind.The fish industry is one of the highest employer of labour in the world. Definitely, water is indispensable to us.

To the fisheries scientists, fish is defined as all life (plants and animals) in the water ranging from the microscopic plants (phytoplankton/microalgae) to the large mammals (whales). This definition is coined from Genesis Chapter 1 verse 26[a], " And God said, "Let us make man in our image, after our likeness: and let him have dominion over the fish of the sea" There are two types of fish: finfish which are the true fish **(**cartilaginous and bony fishes**) and non-finfish [phytoplankton**molluscs (periwinkles, oysters, bloody cockles, clams, mussel, cuttlefish, etc), crustaceans (crabs, prawns, shrimps, lobsters, etc), echinoderms (sea cucumbers, etc), amphibians (frogs), reptiles (alligator, turtles, crocodiles, etc), aves (marine birds such as **penguins**), mammals (marine whales, porpoises, dolphins, **walruses** and seals) and aquatic plants (algae, macrophytes, seaweeds, etc)**. This definition is more encompassing than defining it as** the gill-bearing aquatic craniate or vertebrate animals that lack limbs

5.18 Other Publications

Other publications in the areas of:

Hydrobiology and Limnology

- **Davies, O.A**., Ugwumba, A.A.A. and Abolude, D.S. (2008e). Physico-chemistry quality of Trans-Amadi (Woji) Creek, Niger Delta, Nigeria. *Journal of Fisheries International*, 3(3):91-97.
- Abolude, D.S., Davies, O.A. and Chia, A.M. (2009b). Distribution and concentration of trace elements in Kubanni Reservoir in Northern Nigeria. *Research Journal of Environmental and Earth Sciences*, 1(2):39-44.
- Abolude, D.S., Abdullahi, S.A. and **Davies, O. A.** (2010). Distribution of heavy metals in the tissues of *Bagrus bayad* and *Clarias gariepinus* freshwater fishes. In: Book of Proceedings of Nigerian Institute of Food Science and Technology (NIFST) and 34th Annual Conference, Port Harcourt, Oct. 18[th]-23[rd]. pp 240-241.
- **Keremah R.I., Davies O.A. and Abezi, I. D. (2014). Physico-chemical analysis of fish pond water in freshwater areas of Bayelsa State, Nigeria.** *Greener Journal of Biological Sciences*, 4(2):033-038
- **Davies O.A. and** Teere, M. B. (2018): Effects of radionuclides on aquatic lives of Nigerian Coastal Rivers: A Review. *Journal of Agricultural Sciences and Research*, (In Press).

Fisheries (Fisheries Biology and Management)

- Allison, M.E., Gabriel, U.U., Inko-Tariah, M.B., **Davies, O.A**. and Uedema-naa, B. (1997). The fish assemblage of Elechi Creek, Rivers State, Nigeria. *Niger Delta Biologia*, 2 (1): 53-61.
- Abowei, J.F.N., George, A.D.I. and **Davies, O. A.** (2010). Mortality, exploitation rate and recruitment pattern of *Callinectes amnicola* (De Rochebrune, 1883) from Okpoka

Environmental Sciences (Urban and Rural Planning) and Engineering (Chemical/Petrochemical Engineering, Agricultural and Environmental Engineering, Civil Engineering, Mechanical Engineering and Electrical/Electronic Engineering) and new programmes in Faculties of Agriculture (Agricultural Exension and Rural Development), Education (Educational Management), Management Sciences (Supply Chain and Logistics Management,Tourism and Hospitality Management) and Basic Medical Sciences (Nursing Science). The programme Institute of Foundation Studies was also reviewed and harmonized. However, Mr. Vice-Chancellor, Sir, programmes of two proposed Faculties, Humanities (English Language and Literature in English, History and International Diplomacy, Theatre and Film Studies, French, Philosophy and Religious and Cultural Studies, and Social Sciences (Economics, Pyschology, Political Science, Sociology, Peace and Conflict Studies, Social Works and Gender Studies and Geography and Environmental Management) were reviewed, considered and approved by C&I. All these programmes had been approved by the University Senate.

5.17 Contribution to knowledge through training of skilled fish farmers

Mr. Vice-Chancellor, Sir, we, Roone Venture, AgricBusiness Consultancy, oraganize training workshops and seminars on fish farming. We had trained many people within (EL-Shaddai Bible, Amadi-Ama, Saint Cyprians Anglican Church, Hospital Road, Foundation Faith Church, Rumumasi, Foundation Faith Church, Eneka) and outside Rivers State (Brace Commission,) to become skilled fish farmers.

with digits (true fishes). **Molluscs** and **crustaceans** are referred to as shellfishes. Finfish consists of over 91% of the world's output of food from the aquatic environment.

3.6.4.2 Fishing

Fishing is a gathering skill for catching fish (excluding whales) with appropriate gear or tools and methods or techniques (hand gathering, spearing, netting, angling and trapping) in the wild or open waters and not fish farm (**Davies** and Kwen, 2012). Whaling is the catching of whales.

3.6.4.3 Fisheries

Fisheries, is the plural of the term "**Fishery**" which is the science of producing finfish, shellfish and other aquatic resources. Fishery trade plays an important role in any country. **Major marine products traded are frozen shrimp, frozen fish, frozen cuttlefish/ squid, frozen lobster, chilled items, dried items and shells. Fin fisheries** and **non-fin fisheries** are the two main types of fisheries.

Fin fishery is the fisheries of true fishes (cartilaginous and bony fishes) while **non-fin fisheries** is the fisheries of other aquatic organisms (mentioned above). Finfish consists of over 91% of the world's output of food from the aquatic environment. Fishery trade plays an important role in any country. **Fin Fisheries** and **Non-Fin Fisheries** are further divided into **Capture Fisheries** and C**ulture Fisheries**.

3.6.4.4 Capture fisheries

Capture fisheries is the exploitation of aquatic organisms without stocking the seed in natural aquatic environments (seas, rivers, lakes, creeks, etc)

(**Davies, 2009a; Davies** and Kwen, 2012; **Davies** and Okadi, 2012; **Davies** and Kwen, 2013**). It can also be defined as the catching of fishes, prawns, lobsters, crabs, molluscs, etc. There are two types of capture fisheries: inland capture fisheries and marine capture fisheries which are carried out by use** of non-mechanized (traditional) and mechanized fishing crafts. **Recruitment of species occurs naturally. There are indiscriminate catching of fish including brooders and juveniles, use of unacceptable or unconventional or inappropriate fishing methods, no closed fishing season, overfishing, prone to pollution and environmental factors. Overfishing destroys the fish stocks. Pollution and environmental factors influence the fish yields.**

Capture fisheries has attained the highest limit of exploitation level, and increasing supply from aquaculture sector is seen as the way out to maintain the human fish consumption. The global production of finfish, crustaceans, molluscs and other aquatic animals grew to reach 170.9 million tonnes in 2016. Of this total, capture production was 90.9 million tonnes, a decrease of 1.9 percent compared with the previous year FAO (2018). In 2016, the world total marine catch was 79.3 million tonnes, representing a decrease of almost 2 million tonnes in comparison to 2015.

3.6.4.5 Culture fishery or Culture–based fishery

Culture fishery is a type of fishery in which a part of the life history of certain species is controlled in natural environments by transplanting or releasing their seed or fry into the open waters. The seeds (fry, fingerlings and juveniles) are produced in hatcheries, are released into

5.15 Contribution to knowledge through research fellowships and recognition of works

Mr. Vice-Chancellor, Sir, I won a very competitive research fellowship of the African Women in Agricultural Research and Development (AWARD) as the first Nigerian Fisheries Scientist Post-Doctorate Fellow between 2009 and 2011. I further won the the most competitive second leg of this fellowship for a 9-month research attachment at the Shrimp Genetic Improvement Centre, Phumriang, Chaiya, Surat Thani, Thailand in 2011. I gained tools and skills on domestication of d**omestication and selective breeding program of the black tiger shrimp *Penaeus monodon and*** all male tilapia, *Orechromis niloticus*. I am also a fellow of the Netherlands Government Fellowship Programme (NFP) for Competing Claims On natural Resources Course (2010).

One of my works was recognized by Chicago Council on Global Affairs- Recognition for contribution to the project “Girls Grow: A Vital Force in Rural Economies” - Great synopsis of AWARD Fellowship.

5.16 Contribution to knowledge through Chairmanship of Senate Curriculum and Instructions (C&I) Committee

Mr. Vice-Chancellor, Sir, I very grateful for appointing me as the Chairman, Senate Curriculum and Instructions (C&I) Committee in October 2016. That position has enabled me to use my skill as an Animal Auditor/Reviewer and Editor-in-Chief, Journal of Aquatic Sciences to perform my duties as the Chairman of C&I. By God's grace, my able team, C&I members and I had reviewed some old programmes in Faculties of Agriculture (all programmes), Science (Medical Laboratory Science, Chemistry, Physics, Animal and Environmental Biology, Microbiology, Plant Science and Biotechnology), Education (Library and Information Science, Science Education, Vocational and Technology Education),

5.12 Contribution to knowledge through editorship of reputable journals

I am the Editor-in-Chief (first female) for Journal of Aquatic Sciences (a journal published by the Association for Aquatic Sciences of Nigeria) from 2012-date with foreign subscribers. It is an indexed journal by African Journal Online. During my tenure, I have been able to open a functional website for the journal and publish 4 issues per year from one per year being published by my predecessor.

5.13 Contribution to knowledge through Chapters in research books

Mr. Vice-Chancellor, Sir, my friend and I have contributed to knowledge on shrimp farming through a chapter in research book titled "Breeding and management of shrimps in the tropics" (Chapter 3). In: Aiyelola, A.A. and Ijeomah, H.M. (Eds). Book of Reading in Forestry, Wildlife Management and Fisheries by Ansa and **Davies** (2011). A book published by Topbase Nigeria Limited, Lagos in conjunction with Green Canopy Consultants, Port Harcourt.pp1055-

5.14 Contribution to knowledge through minor other productive works

Mr. Vice-Chancellor, Sir, My English Teacher in Secondary School (Onireke High School, Ibadan), Mr. Alabi, encouraged me to write and publish two articles within the scope of Zoology before the completion of master's programme titled as follows:

> "Breeding bush meat for consumption and commerce- Snails" by **Bubu, O.A.** (1993). An article published in *Agric today* (*Nigeria's Agribusiness Magazine*), Volume 1 number I, p 7.

> "Breeding bush meat for consumption and commerce–Giant Rat (*Cricetermys gambianus*)" by **Bubu, O.A.** (1993). An article published in *Agric Today (Nigeria's Agribusiness Magazine*), Volume 1 number I, p10.

fresh, brackish or marine waters and allowed to propagate or grow on natural foods until they reach harvestable size. Culture–based fisheries is a means of enhancing the fishery resources, replenishing natural stocks whose populations have declined through over-exploitation or environmental degradation, or simply maximizing the productivity of a water body, be it an open bay, a coastal lagoon, or a freshwater reservoir. Surely, water is indispensable. 107There are four types of culture-based fisheries namely: sea/ocean ranching, coastal lagoon farming, stocking and restocking in freshwater lakes and reservoirs and floodplain fisheries management.

3.6.4.6 Aquaculture

Aquaculture is the cultivation of aquatic life within controlled environments or the commercial production of certain aquatic species by managing the major part of their life history under strict control. **Aquaculture is the application of biological principle** to business of farming (involving breeding, raising and harvesting) aquatic plants or animals in controlled conditions, in all types of artificial water environments or enclosures that retain water (Ugwumba *et al*., 1995; **Davies** *et al*., 2006a; **Davies** *et al*., 2006b; **Davies** *et al*., 2008c; **Davies** and Ezenwa, 2010; **Davies** *et al*., 2013a). Wow, water is indispensable!

At this junction, a hydrobiologist can be said to be an aquaculturist based on the facts that he/she has good insight of the biology especially habitats, reproduction and food and feeding habits (nutrition) of any water organism. **Who said I am not an aquaculturist? I am aquaculturist: I have in-depth knowledge of the**

biology of aquatic organisms. I can culture any of them effectively with my biological knowledge. I am applying this biological principle to the production of some of these organisms in my research (Ugwumba, Ugwumba, Sowunmi, **Bubu** and Ofuani (1995); Inko-Tariah, Gabriel, Allison and **Davies,** 2001; **Davies** *et al*., 2006a; **Davies** *et al*., 2006b; **Davies** *et al*., 2008a; **Davies** *et al*., 2008b; **Davies** *et al*., 2008c; **Davies** and Ezenwa, 2010; Ansa, Hart, Assayomo and **Davies,** 2011; **Abolude, Opabunmi, Davies and Awotoye, 2013**), **teaching and commercial fish farm.**

Controlled conditions are some forms of interventions in the rearing process to enhance production of aquatic organisms, such as regular stocking, feeding and protection from predators, among others. Another word for aquaculture is **fish farming**. There are different types of aquaculture: **Finfish Aquaculture, Shellfish Aquaculture, Other Aquatic Animals Aquaculture and Aquatic Plants Aquaculture.** The last three types of aquaculture are known as **Non-Finfish Aquaculture**. Aquatic organisms are reared either for food fish, medicine, commercial products, sport fish (**angling**, **recreational** purpose), ornamental fish (recreational purpose), bait fish or feed fish or restocking fish (production for fry, fingerlings and juveniles) to purposefully restore and create healthier habitats and rebuild threatened or endangered species populations. Fish farms could be complete (from production of the eggs to full size fish for food or breeding stock) or restricted (only hatchery or nursery or production (for table-sized fish for food or breeding stock). There are two types of aquaculture: **marine** and **freshwater** aquaculture. The practice of culturing plants, fish,

Plate 14: Stocking of all-male tilapia juveniles by Dr. Onome Davies (now Prof. Onome Davies)

5.11 Contribution to knowledge through mentoring

Mr. Vice-Chancellor, Sir, I have many mentees notable among them are Mrs. Anita Benwari (Nee Ozolua) (University Lecturer, AWARD Mentee), Mrs. Ogidiaka-Obende Efe (Nee Ogidiaka, Tertiary Institution Lecturer, The World of Science 2017 Fellow), Dr. Augustina Okereke (Research Officer, Australian Award in African Fellow, NFP Fellow and Institute of Development Studies Brighton UK Fellow), Mrs. Nora Weli (Nee Aririsukwu, Fisheries Extensionist), Mr. Cedric Iyalagha (Environmental Scientist), Dr. Dokuboba Amachree, Dr. Tonbarapagha Kingdom (Associate Professor, Niger Delta University), Dr. Benjamin Otene, Mr. Okpaku Tamuno Ajubo (Environmental Scientist), Chief Keme-Iderikumo Kwen (NIFFR Fisheries Researcher), Chief Daniel Okadi and Mr. Felix Nweke (Fisheries Scientist).

Plate 13c) and fed to table size for food fish. Records of inputs and outputs were noted. The table-size fish were sold as a proof of profitability of fish farming. This also motivated the students to stu5 Fisheries or staff to invest on fisheries business. The Head Teacher of Agricultural Science, Mr. Barida Yorka is the beneficiary of this project, as he is now trained and skilled Fish Farmers.

Plate 13a: Cottage Fish Farm at ISS, behind the then Vice-Principal Academics Office

Plate 13b: Stocking of Catfish juveniles

Plate 13c: Stocking of all- male tilapia juveniles

5.10 Contribution to knowledge through donation of all male *tilapia, Orechromis niloticus seeds*

Mr. Vice-Chancellor, Sir, I donated all male tilapia, *Orechromis niloticus* seeds in March 2012 (Plate 14) to the Aquaculture Centre of the Department of Fisheries and Aquatic Environment as output of my post doctorate research on all male tilapia and shrimps (giant tiger shrimps, *Penaeus monodon*) in Thailand. They were cultured to table size for food fish and sold to the University Community in December 2012.

shellfish and other aquatic life under controlled conditions started over 4000 years; it was practiced in China and the Indopacific region for at least 2000 years B.C; It started in 1950 in Nigeria and in 1962 in the Niger Delta. Aquaculture in Nigeria evolved from a non-traditional innovation in most parts of the country to a well-understood production system.

Aquaculture production is growing at an ever-increasing rate from less than one million tonnes in 1950s to fifty-five million tonnes in 2009, increasing at three times the rate of world meat production, 2.7% from poultry and livestock together with an average annual growth rate of 8.3% world wide (FAO, 2010). Aquaculture is growing at the rate of 9% annually unlike capture fisheries due to overfishing and ever-increasing human population and demand (FAO, 2016). The global production of finfish, crustaceans, molluscs and other aquatic animals grew to reach 170.9 million tonnes in 2016. Out of this total, aquaculture production was 80 million tonnes in 2016, up by 5.2% from previous year (FAO, 2018). The average annual growth rate of world aquaculture production during 2001-2016 was 5.8%, significantly lower than what was experienced in the 1980s (10.8%) and in the 1990s (9.5%). The annual growth rate in 2016 was 5.2%. The contribution of aquaculture to the total production of capture and aquaculture combined has risen steadily from 25.7% in 2000 to 46.8% in 2016. The world production of aquatic plants, mostly seaweeds, reached 31.2 million tonnes in 2016, of which 30.1 million tonnes (96.5%) was harvested from aquaculture (FAO, 2018). Water is indispensable! Aquaculture is the fastest growing segment of agriculture in the United States today unlike Nigeria but with consumer demands for seafood increasing, interest in aquaculture as a means for satisfying the demands coupled with the prospects for commercial aquaculture are becoming promising.

3.7 Profitability (Benefits) of studying Hydrobiology and Fisheries (Career Opportunities)

It is profitable to study and practice Hydrobiology and Fisheries. It is a blessed discipline according to Genesis Chapter 1 verse 22[a] "And God blessed them, saying, "Be fruitful and multiply, and fill the waters in the seas". Also, a profession recognized by God with occasional instance in the bible where fish has transformed life (Matthew Chapter 17 verse 27[b] "Go thou to the sea, and cast an hook, and take up the fish that first cometh up; and when thou hast opened his mouth, thou shalt find a piece of money: that take, and give unto them for me and thee").

Graduates of this discipline will find employment opportunities in the following sectors of our economy as aquatic biologists, farm managers and technicians, policy makers, research scientists, lecturers, wild fisheries officers, aquaculturists, ownership of environmental firms, environmental scientists, consultants and aquaculture consultants:

- ❖ Federal and State Ministries of Environments, Agriculture and Research Institutes.
- ❖ Public and Private Oil and Non-Oil Related Industries (Fishing, Processing and Marketing Industries).
- ❖ Higher Institutions (Public and Private).
- ❖ Maritime and Oceanographic Institutes.
- ❖ Entrepreneurship.

Plate 12a: Role Model (Then Dr. Onome A. Davies)

Plate 12b: SAVC, Principal ISS & Staff Sch Agric.Teacher

Plate 12c: Mrs. Daminabo & Mrs. Anyanwu

12d: Mrs. Daminabo presenting Prof. B.B. Fakae's speech

Plate 12e: Principal ISS (Elder Bara-Hart) presenting his speech

Plate 12f: Dr. Onome Davies presenting her paper

Plate 12g: Role Model, Vice-Principal (Admin) & ISS students

Plate 12h: Dr. Onome Davies, Dr. Ebinimi Ansa, Dr. Elsie Halmadina, Dr. Jumoke Edun, Dr. Victoria Agokei, Mrs. Anyanwu

5.9 Contribution to knowledge through establishment of Cottage Fish Farm at ISS

Mr. Vice-Chancellor, Sir, in addition to the role modeling event at ISS, I established a Cottage Fish Farm to demonstrate that fish farming is feasible and profitable in March 2012 during my tenure as the Chairperson, ISS Teaching Farm (Sub-committee of ISS Management Committee). I stocked catfish, *Clarias gariepinus* and all male tilapia, *Orechromis niloticus* seeds into to two plastic containers (Plates 13a-

5.8.1.7 Davies and Davies (2017b) evaluated the combustion **characteristics of briquettes produced from sawdust and phytoplankton scum.** The study acknowledged briquettes produced from **sawdust and phytoplankton scum** provides excellent ignition time, specific fuel consumption, burning rate thermal fuel efficiency, calorific values and water boiling time.

5.9 Contribution to knowledge through role modelling event

Mr. Vice-Chancellor Sir, I organized a ground breaking and life-changing Role Modelling Event on Thursday 9th December, 2010 at the International Secondary School (ISS), Rivers State University as one of my duties as an AWARD PostDoctorate Fellow (Plate 12a-12h). The event was 100% sponsored by AWARD and supported by Rivers State University (event honoured by the former Vice-Chancellor, ably represented by the former Special Adviser to the Vice-Chancellor (SAVC), Mrs. Daminabo and evented fully covered by the University Publication Relations Units headed by former Deputy Registrar of the unit, Chief Desmond Wosu). I pooled the University Staff School pupils and the ISS student for this event. I presented my success story. I strong believe that noble event is yielding dividends, one of which is the increasing school enrollment in the Faculty of Agriculture especially in the Department of Fisheries and Aquatic Environment from 2012/2013 till date (2012/2013 [8]; 2013/2014 [24]; 2014/2015 [28]; 2015/2016 [28]; 2016/2017 [16] and 2017/2018 [41]). I am glad to inform you that two of the pupils from Staff in 2010/2011 are studying Agriculture in this University; Glory Amadi, my Year IV Student and, Omosewa Gloria Williams, Year I Crop/Soil student.

4.0 NIGERIAN INLAND WATERS

4.1 Nigerian aquatic environments

The hydrological map of Nigeria showing the major inland water bodies is presented in Fig. 2. It is dominated by two great river systems called Niger-Benue and the Chad systems. Few of the inland

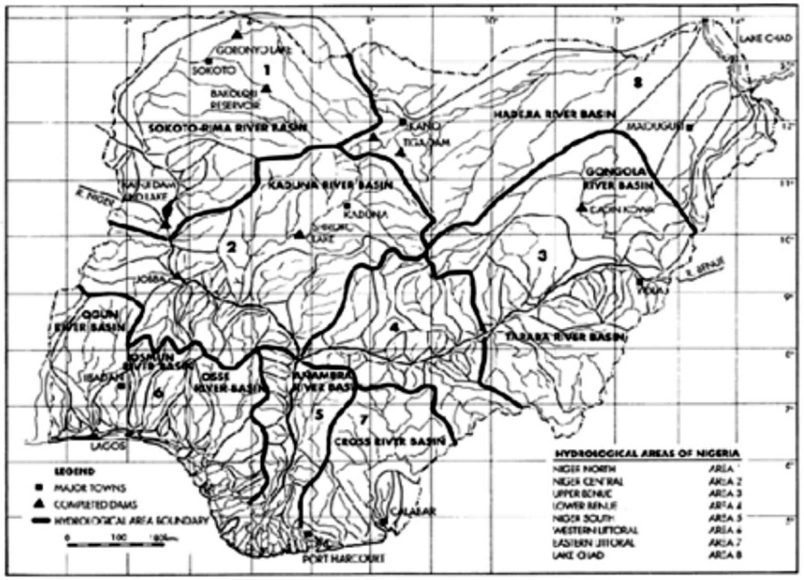


Fig.2: Hydrological map of Nigeria showing the major inland waters
Source: http://www.fao.org/docrep/005/T1230E/T1230E02.htm

4.2 Major water resources of Nigeria

Nigeria is located between Longitudes 2°49'E and 14°37'E and Latitudes 4°16'N and 13° 52' North of the Equator. Its climate is tropical with characterized high temperatures and humidity, marked wet and dry seasons but with variations between South and North. The total rainfall decreases from the coast northwards thus we experience more rains in Rivers, Bayelsa, Delta, Cross Rivers, Akwa Ibom and Lagos States. The South (below Latitude 8°N) has an annual rainfall ranging between 1,500 and 4,000 mm and the extreme North between 500 and 1000 mm.

Nigeria is blessed with many inland freshwater and brackish ecosystems. It has an extensive mangrove ecosystem found within the Niger Delta especially in Rivers, Delta, Cross River, Akwa Ibom, Lagos and Ondo States. Table 2 shows the major inland water resources of Nigeria while Table 3 indicates the distribution and extent of Nigerian brackish and freshwater bodies.

Table 2: Major inland water resources of Nigeria

Types of water bodies	Approximate surface area (ha)
A: Major Rivers	
i) Anambra River	1,401,000
ii) Benue River	129,000
iii) Cross River	3,900,000
iv) Imo River	910,000
v) Kwa Iboe River	500,200
vi) Niger River (less Kainji and Jebba lakes)	169,800
vii) Ogun River	2,237,000
viii) Oshun River	1,565,400
Sub-total	10,812,400
B: Major Lakes and Reservoirs	
i) Lake Chad (natural)	550,000
ii) Kainji Lake (man-made)	127,000
iii) Jebba Lake (man-made)	35,000
iv) Shiroro Lake (man-made)	31,200
v) Goronyo Lake (man-made)	20,000
vi) Tiga Lake (man-made)	17,800
vii) Chalawa Gorge (man-made)	10,100
viii) Dadin Kowa (man-made)	29,000
ix) Kiri (man-made)	11,500
x) Bakolori (man-made)	8,000
xi) Lower Anambra (man-made)	5,000

5.8.1.4 The paper on physical characteristics of some biomass briquettes by Davies and Davies (2014a) investigated the effect of binder types and concentration on the physical quality of **water lily briquettes**. The findings of this study showed that briquettes produced from water lily and agricultural wastes (peels of plantain, banana, yam and cassava) as binding agents meet recommended quality for commercial briquettes. The study showed that among all the utilized binding agents, cassava peels had the highest physical and mechanical handling characteristics.

5.8.1.5 Davies and Davies (2017a) assessed the **frictional characteristics of some water lily pellets.** The pellets were produced using two aquatic weeds (**water lily and phytoplankton**) and agricultural wastes (banana peels, cassava peels and yam peels as binders). The study identified that briquettes produced from water lily had better frictional characteristics that those from phytoplankton.

5.8.1.6 The publication on some physical and mechanical properties of **water lettuce** (*Pistia stratiotes*) briquettes by Davies and Davies (2014b) evaluated the different briquettes produced from water lettuce and some agricultural wastes (peels of plantain, banana, yam and cassava) as binding agents. The findings of this study revealed that briquettes produced from water lettuce and agricultural wastes had high water resistance capacity, compressive strength, densification ratio and durability and also environment friendly. The briquettes produced compared favourably with firewood, mangrove wood and charcoal.

5.8.1.2 Davies *et al*. (2013) assessed the combustion characteristics of traditional energy sources and **water hyacinth briquettes. The** briquettes were produced from mixed water hyacinth and plantain peels as binder and compared with mangrove wood, charcoal and *Anthronotha macrophylla* (firewood). Combustion characteristics investigated were calorific values, ignition time, burning rate, specific fuel consumption, fuel efficiency and water boiling time. This study demonstrated that briquettes can be utilized instead of other traditional fuel energy for domestic and industrial applications. The water hyacinth briquettes possess high material strength which qualified them as alternative to firewood and charcoal for domestic and industrial energy.

5.8.1.3 The physical and combustion characteristics of briquettes made from **water hyacinth** and **phytoplankton scum** as binder were determined by Davies and Davies (2013) (Plates 11a-11c). The optimum binder level required to produce the briquettes with the highest durability strength is 50% binder ratio. The best shatter and durability indices showed that they have good shock and impact resistance and are good for handling and transportation.

Plate 11a: Dried water hyacinth

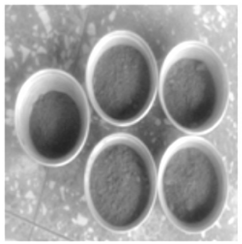


Plate 11b: Dried phytoplankton scum

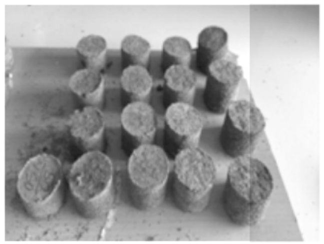


Plate 11c: Briquettes produced from water hyacinth

xii) Zobe (man-made)	5,000
xiii) Oyan (man-made)	4,000
Sub-total	853,600
Total A+ B	11,666,000
A + B as % of total area of Nigeria (94,185,000ha)	12.4%

Source: http://www.fao.org/docrep/005/T1230E/T1230E02.htm

Table 3: Distribution and extent of Nigerian brackish and freshwater bodies

Types of wetland and distribution	Approximate size (ha)
1. Deltas and estuaries	
i) Niger delta	617,000
ii) Cross River estuary	95,000
iii) Imo and Qua Iboe estuary	36,000
iv) Others	110,000
Sub-Total	858,000
2. Freshwaters	
i) Niger delta freshwater	362,000
ii) Apex of delta to Lokoja	635,000
iii) Niger/Sokoto Basin	470,000
iv) Niger Kaduna Basin	150,000
v) Lower Niger: Jebba to Lokoja	385,500
vi) Benue River floodplain	312,000
vii) Hadejia Komadugu Yobe	624,000
viii) Ogun/Oshun floodplains	Not estimated
ix) Cross River floodplains	250,000
x) Imo River floodplains	26,000
xi) Kwa Iboe	7,000
Sub-Total	3,221,500
3. Other freshwaters	
i) Minor reservoirs	98,900
ii) Fish ponds	5,500
iii) Miscellaneous wetlands suitable for rice cultivation	4,108,100
Sub-Total	4,212,500
Surface area of Nigeria	94,185,000
1. as % of total area of Nigeria	1.0%
2. as % of total area of Nigeria	3.4%

Source: http://www.fao.org/docrep/005/T1230E/T1230E02.htm

4.3 Major biological resources of Nigeria (aquatic plants and wetland wildlife resources)

Biological resources in waters are results of primary production majorly by phytoplankton (**Davies** *et al*., 2009a) and to a limited extent by periphyton and macrophytes (**Davies** and Ugwumba, 2013a) which depend on nutrient status, chloroplast pigments, dissolved carbon dioxide and available light energy. Nigeria is very rich in biological resources namely flora (plants) and fauna (animals) as indicated in section **3.2.3**.

My Ph.D. research work on the phytoplankton, epiphyton, zooplankton and finfish assemblages of Okpoka Creek contributed immensely to the biological resources data of the Niger Delta, Nigeria. Okpoka Creek of the Upper Bonny Estuary in Port Harcourt, Rivers State is one of the Nigerian water resources (inland waters) and contributes to Rivers State fish resources. As at May 2004 to April 2006 I conducted my Ph.D. research work, there has been very little information on the biotic and abiotic factors of this Creek thus my work bridged the existing gap in knowledge of the biotic and abiotic features of this estuary.

4.3.1 Phytoplankton of Nigeria

The phytoplankton assemblage of Okpoka Creek represents the phytoplankton species composition, diversity, abundance and distribution of Nigerian inland waters (Figs. 3-7 and Tables 4-5). They are primary live food for herbivorous animals and non-photosynthetic phytoplankton.

of smoke-dried fish were mangrove (7.46±0.05) briquettes (7.27±0.06), charcoal (6.82±0.04) and common wood (6.93±0.26). The observed results in terms of taste for the four energy sources revealed high acceptability (scores >6). Fish smoke-dried with charcoal (6.55±0.13) recorded the lowest appearance and briquettes highest acceptability (7.59±0.22). The observed results in terms of appearance for the four energy sources revealed high acceptability (scores > 6). The texture of the fish smoke-dried with briquettes, charcoal, common wood and mangrove had acceptability of 7.40±0.13, 7.12±0.22, 7.34±0.22and 7.34±0.13. Texture acceptability of smoke-dried fish with the four energy sources was high (scores >7). The interpretation of this observation is that fuel used in smoking process had no effect on the texture of the smoke-dried fish. The specific fuel consumption (kg fuel per kg fresh fish) revealed mangrove wood had 0.2, firewood 0.29, charcoal 0.16 and briquette 0.15. The mean fuel charge required to smoke one kg fresh fish for briquettes was 0.15 kg, charcoal was 0.16 kg, red mangrove wood was 0.2 kg and 0.24 kg for common wood. The cost per kg of fuel of each of the energy sources was for smoking was mangrove wood, 45.50 per kg; firewood, 41.9 per kg; charcoal, 51.20 per kg and briquette, 23 per kg. The total cost of fuel for smoke processing for all the energy sources was mangrove wood, 589.50; common wood, 493.76; charcoal, 428.40 and 222.07 for briquette. The energy sources used in smoking 1 kg fresh fish for mangrove was 9.07, common wood, 9.95, charcoal 8.27 and briquettes 3.42.

In Niger Delta, the average weight or volume of fuelwood used per day (16.45 kg or 7.5m^3) exceeds the Food and Agriculture Organization (FAO) average allowance (0.46 m^3). Mangrove (*Rhizophora racemosa, Avicennia nitida*) wood is the predominant source of fuel available to the fish processors in the riverine fishing communities and *Anthonotha macrophylla* wood for the upland fishing communities (Davies *et al.,* 2009). The abundance, availability, low cost, and rapid growth of water hyacinth make them an ideal candidate for biofuel, particularly in the developing countries. Over dependent on mangrove trees as source of fuel has led to serious deforestation which has destroyed the ecosystem. Mangroves have been over-depleted and fuelwood price has gone up. Davies and Davies (2009) reported that fuelwood (50%) was highly preferred energy source for fish processing followed by charcoal (21%), wood shaving (17%), sawdust (14%) and electricity and gas (2%). The estimated total annual consumption of wood in Nigeria is at about 50 to 55 million cubic meters of which 90% is fuelwood (NEST, 2001). The world's energy demand is not met by fossil fuel mainly coal, crude oil and natural gas (Emerhi, 2011).

5.8.1.1 A study was carried out by Davies and Davies (2012) investigated the **organoleptic (**colour, appearance, texture and taste acceptability) **and economic appraisal of fish smoked with water hyacinth briquettes and traditional energy sources. That study revealed** that the water briquettes competed favourably with **charcoal, common wood (*Anthronotha macrophylla*) and red mangrove wood** in terms of colour, appearance, texture and taste acceptability as well as cost of fuel. The organoleptic parameters of fish smoked with different energy sources were similar. The recorded results of taste acceptability

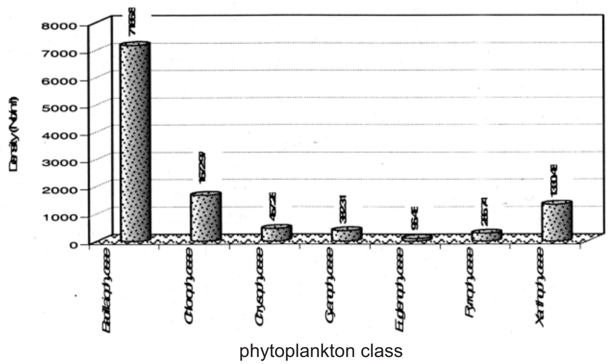


Fig. 3: Phytoplankton density in Okpoka Creek
Source: Davies (2008)

Table 4: Checklist and percentage distribution of Bacillariophyceae species in Okpoka Creek

S/No.	Species	Percentage distribution (%)	S/No.	Species	Percentage distribution (%)	S/No.	Species	Percentage distribution (%)
1	*Cyclotella comta*	10.89 ± 1.32	28	*N. bilobata*	11.39 ± 1.95	55	*Cymtopleura species**	0.27 ± 0.00
2	*C. meneghiniana*	9.34 ± 0.97	29	*N. lanceolata*	8.50 ± 2.45	56	*Campylodiscus hibernicus*	1.16 ± 0.00
3	*C. striata*	7.31 ± 1.24	30	*N. paradoxa*	6.83 ± 0.60	57	*Pinnularia viridis*	2.03 ± 0.73
4	*C. operculata*	17.24 ± 1.63	31	*N. filiforms*	11.33 ± 0.85	58	*P. horealis*	2.90 ± 0.82
5	*C. species**	3.96 ± 0.32	32	*N. longissima*	10.17 ± 0.00	59	*P. major*	0.87 ± 0.33
6	*Fragilaria intermedia*	1.94 ± 0.54	33	*N. species**	7.08 ± 3.47	60	*P. species**	6.69 ± 1.10
7	*F. capucina*	2.66 ± 1.59	34	*Navicula gracilis*	7.15 ± 1.54	61	*Frustulia rhomboides*	7.35 ± 0.96
8	*F. construens*	0.39 ± 0.00	35	*N. cuspidate*	10.74 ± 1.60	62	*Gyrosigma acuminatum*	7.24 ± 0.75
9	*F. species**	3.02 ± 0.00	36	*N. placentula*	10.09 ± 0.60	63	*G. species**	15.76 ± 0.00
10	*Epithermia zebra*	0.47 ± 0.00	37	*N. microcephala*	10.33 ± 1.72	64	*G. attenuatum*	11.46 ± 0.00
11	*Attheya Zacharias*	0.79 ± 0.00	38	*N. bacillum*	11.37 ± 1.18	65	*G. paradoxa*	3.53 ± 0.00
12	*Stauroneis acuta*	3.21 ± 0.00	39	*N. amphibola*	0.37 ± 0.00	66	*Stephanodiscus astrae*	6.10 ± 1.07
13	*S. parvula*	2.71 ± 0.00	40	*N. species**	9.53 ± 2.95	67	*S. species**	1.70 ± 0.00
14	*S. species**	1.97 ± 0.00	41	*Melosira varians*	12.54 ± 0.73	68	*Cocconeis placetula*	0.38 ± 0.00
15	*Diatoma vulgare*	4.35 ± 0.77	42	*M. undulata*	26.03 ± 16.05	69	*Bacteriastrum*	0.10 ± 0.00
16	*Rhizosolenia sp*	0.65 ± 0.36	43	*M. pusilla*	17.66 ± 0.96	70	*Bacillaria species**	1.57 ± 0.00
17	*Tabellaria fenestrate*	1.62 ± 0.26	44	*M. distans*	12.16 ± 4.13	71	*Biddulphia species**	0.30 ± 0.00

other avian migrants. Aquatic plants as biofertilizers, source of energy (biogas, solid fuel/briquettes/biochaocoal, innovative industrial materials (for construction, water treatment, biomonitoring agents, brewing, matting, bedding, perfume, mosquito repellent, particle board, fibre and pulp/paper). Aquatic plants as a source of food fodder (rice, *Oriza sativa*, *O. longistaminata*) for man and livestocks; seeds burgu (*Echinochloa stagnina*; rhizome, floral receptacle and fruits of *Nymphaea lotus* (water lily) are eaten raw or cooked for food and *Ludwigia stolonifera* is used as an soup ingredient); mangrove palm (*Nypa fruticans*) for alcohol, sugar and vinegar; and medicine (ethnobotanic materials) for modern drugs and pharmaceuticals; the barks of mangrovs for diarrhoea or dysentery, to check haemorrhage, sore throat and urethral infection, leprosy and craw craw. Aquatic plants have been used for habitat protection and nature conservation (to avoid the over-use of land resources in one location through nomadism and transhumance) as well as recreation, tourism, aesthetic and other uses.

Niger Delta of Nigeria is characterized by extensive network of rivers and creeks which discharge their waters into the Atlantic Ocean. Water hyacinth (*Eichhornia crassipes*) is one of the most invasive and prolific aquatic weed. It smoothers and devastates lakes, canals, rivers and pond. It chokes other aquatic lives, prevents navigation, favour mosquitoes breeding. It fosters water borne diseases, environmental nuisance and threat to eco-diversity in the Niger Delta. This aquatic weed blooms heavily in Niger Delta due to favourable climatic condition (Davies and Davies, 2016). The harvest frequency for aquatic plants tends to be in the order of days, whereas the frequency for trees and crops are the order of years and months.

estimated to be 39 million tonnes of fuelwood. About 95% of the total fuelwood consumption was used in the households for cooking and for cottage industrial activities and 5% for services sectors (Sambo, 2009). According to Adegbulugbe (1994) about 350,000 hectares of forest and natural vegetation are lost annually due to various factors, by the beginning of the last decade, with much lower afforestation rate of 50,000 hectares per year. One of the most important energy sources for mankind is biomass which is referred to all organic materials particularly wood and agricultural residues. Therefore, biomass energy has been attracting attention as an energy source since zero net carbon dioxide accumulation in the atmosphere from biomass production and utilization can be achieved.

Fossil fuel (non-renewable) provides about 80% of man's energy sources now and this may start to depreciate in the next twenty to thirty years. A briquette is a block of compressed coal, biomass or charcoal dust that is used as fuel (Davies *et al*., 2013). Briquetting is a high pressure process which can be done at elevated temperature or at ambient temperature depending on the technology applies.If biomass or agro-waste briquettes are to be used efficiently and rationally as fuel, they must be characterized to determine parameters such as combustion rate, ignition time and burning rate, moisture content, ash content, density, volatile matter, and heating value amongst others. Combustion of briquettes is environment friendly. The smoke by firewood and mangrove wood causes multiple respiratory illness (Davies *et al*., 2013). Briquettes are smokeless and burn clean.

5.8.1 Studies on utilization of aquatic plants as a source of renewable energy

Aquatic plants are used in Nigeria are as live food for man, fin and shell fish and other animals, breeding grounds for a large number of insects and other invertebrates which serve as fish food, spawning and breeding grounds as well as shelter for fish fry, nesting sites for various species of game birds, waders and

18	*Synedria ulna*	12.08 ± 1.71	45	*M. listans*	9.08 ± 0.99	72	*Corethron hystrix*	10.82±0.00
19	*S. acus*	4.51 ± 0.69	46	*M. granulate*	1.60 ± 0.00	73	*Cylindrotheca species**	4.67 ± 0.00
20	*S. affinis*	7.29 ± 1.55	47	*M. species**	0.77 ± 0.00	74	*C. gracillis*	2.67 ± 0.00
21	*S. species**	10.26 ± 1.26	48	*Cymbella cuspidata*	2.34 ± 0.82	75	*Diploneis species**	0.07 ± 0.00
22	*Cosinodiscus lacustris*	9.46 ± 1.00	49	*C. lata*	2.20 ± 0.00	76	*Ditylum species**	0.10 ± 0.00
23	*C. radiate*	6.39 ± 1.18	50	*Aterionella formosa*	0.84 ± 0.00	77	*Hydrosera species**	1.00 ± 0.00
24	*C. excentricus*	0.96 ± 0.00	51	*Surirella species**	2.41 ± 0.00	78	*Skeletonema species**	0.84 ± 0.00
25	*C. species**	7.41 ± 6.61	52	*S. tenera*	1.25 ± 0.70	79	*Thalossiothrix species**	0.13 ± 0.00
26	*Amphora ovalis*	2.68 ± 0.54	53	*S. elegans*	0.99 ± 0.00	80	*T. longissimum*	0.17 ± 0.00
27	*Nitzchia sigma*	15.15 ± 1.64	54	*S. robusta*	5.49 ± 2.08			

*Unidentified **Source: Davies (2008)**

Table 5: Checklist and percentage distribution of Chlorophyceae species in Okpoka Creek

S/No.	Species	Percentage distribution (%)	S/No.	Species	Percentage distribution (%)	S/No.	Species	Percentage distribution (%)
1	*Microspora villeana*	22.35 ± 2.33	16	*S. natator*	14.29 ± 0.00	31	*Desmidium grevillii*	1.52 ± 0.51
2	*Spirotaenia species**	11.88 ± 4.12	17	*Closterium dianae*	6.18 ± 0.02	32	*D. aptogonum*	8.62 ± 3.19
3	*Coelochaeta nitellarum*	76.16 ± 16.16	18	*C. parvulum*	16.16 ± 2.49	33	*Planktosphueria gelatinosa*	5.21 ± 0.12
4	*Mesotaenium species**	16.08 ± 8.17	19	*C. gracile*	7.81 ± 1.75	34	*Netrium digitus*	44.19 ± 4.72
5	*Entransia dichloroplastes*	23.85 ± 16.16	20	*C. kuetzingii*	2.36 ± 0.00	35	*Treubaria crassispina*	1.72 ± 0.00
6	*Chactosphora species**	1.47 ± 0.00	21	*C. macilentum*	1.81 ± 0.00	36	*Bulbochaeta species**	20.48 ± 12.86
7	*Tetraedron tumidulum*	7.53 ± 2.51	22	*C. strigosum*	4.72 ± 0.00	37	*Closteridium lunula*	12.90 ± 0.44
8	*Tetmemorus species**	1.77 ± 0.00	23	*Cosmarium species**	7.14 ± 0.00	38	*Docidium species**	7.62 ± 0.00
9	*Penium species**	2.07 ± 0.00	24	*C. granatum*	11.40 ± 8.60	39	*Ankistrodesmus species**	44.44 ± 0.00
10	*Crucigenia rectangularis*	21.47 ± 2.83	25	*Cladophora glomerata*	15.94 ± 2.52	40	*Oedogonium species**	7.41 ± 0.00
11	*C. fenestrata*	36.39 ± 2.70	26	*C. elegans*	12.21 ± 2.98	41	*Scenedesmus species**	38.33 ± 0.00
12	*C. puadrata*	13.65 ± 3.62	27	*Draparnaldia species**	42.39 ± 21.92	42	*Spirogyra species**	14.82 ± 0.00
13	*Gonatozygon aculeatum*	29.69 ± 3.23	28	*Celatrium micromium*	20.04 ± 9.14	43	*Cladophora species**	2.07 ± 0.00
14	*G. species**	12.18 ± 6.39	29	*C. recticulatum*	16.62 ± 3.28	44	*Netrium species**	17.15 ± 2.86
15	*Staurastrum grande*	5.90 ± 2.21	30	*Rhizodonium hookeri*	12.98 ± 0.36			

*Unidentified **Source: Davies (2008)**

natural water bodies thus Trans-Amadi creek, Port Harcourt is organically polluted with total coliform bacteria. The observed high temperature, conductivity, total dissolved solids, chloride, phosphate and ammonia favour the growth, survival and multiplication of coliform bacteria. Also, the presence of high amount of human faeces, animal dungs and refuse enhances bacterial pollution in this creek. The dry season coliform bacterial counts (5,621 cfu/ml) were higher than wet season (4,830 cfu/ml). Tide had significant effect on bacterial count with higher value at high tide (5,795 cfu/ml) than at low tide (4,631 cfu/ml).

5.7 Contributions to impacts of sand dredging studies on aquatic life

Ekeke, Alfred-Ockiya and **Davies** (2008) work on sand dredging impact on the fish catch in Bonny River Estuary, Nigeria recorded 45 fish species (finfishes and shellfishes) from 33 families. The finfish species were Ariidae, Bagridae, Cichlidae, Clupeidae, Carangidae, Cynoglossidae, Dasyatidae, Ephippidae, Lutjanidae and amongst others. The observed shellfish families were Portanidae, Palaemonidae, Muricidae, Crassostredae, Ocypodidae and Potamidae. The estimated total landing values were higher than the values obtained in previous study. The results revealed that the river system is still a good fishing ground indicating that sand dredging activities had no significant impact on the fish catch and population.

5.8 Contributions to renewable energy

Biomass is an energy resource. Energy is a necessary requirement for everyday life. Its utilization ranges from cooking, local industrial and food processes, warming of the body and other complex industrial and commercial applications. Fuelwood and charcoal constituted between 32 and 40% of total primary energy consumption over the period of 1989-2000 (Sambo, 2009). In year 2000, national demand was

5.5.6 The study of Okereke, Ezeama, **Davies** and Ezeonye (2017a) on effect of depuration on microbial load of mangrove oyster (*Crassostrea gasar*) from a polluted creek in rivers state, Nigeria showed that depuration reduced the high microbial load of the oysters to the standard limit of $1x10^2$cfu/g for faecal coliform and $1x10^5$cfu/g for bacteria and fungi.

5.5.7 The article, Okereke, **Davies,** Ike-Obasi and Ezeonyejiaku (2017b) on effect of depuration on heavy metal (Lead, Chromium, Cadmium and Zinc) concentrations in periwinkle (*Tympanatonus fuscastus*) from a polluted creek in Rivers State, Nigeria documented that 96 hours depuration reduced these metals to acceptable limits for human consumption.

5.5.8 Davies and Daniel (2018) investigated the accumulation of heavy metals (Zinc, Copper and Chromium) in periwinkle (*Tympanotonus fuscatus var radula*) in Amadi Creek by Tourist Beach, Port Harcourt, Rivers State. The results showed that sediments concentrated more heavy metals than the water while the periwinkles accumulated more of these metals than the sediments. The tissue accumulated more of the heavy metals than the shells. The heavy metals in the water and sediments were biomagnified in the periwinkles shells and tissues. The large sized periwinkles accumulated more of the studied heavy metals except Cu than the small sized ones. Zinc was the highest concentrated heavy metal in both the small and large sized periwinkles (Zn>Cr>Cu) and observed value in water exceeded the permissible limit of $\leqslant 0.05$.

5.6 Contributions to bacterial pollution studies

5.6.1 The study of Davies *et al*. (2008d) on the evaluation of total coliform bacteria pollution in Trans-amadi Creek, Niger Delta, Nigeria revealed that total coliform bacterial counts exceeded the maximum permissible limit of >0.1 cfu/ml for

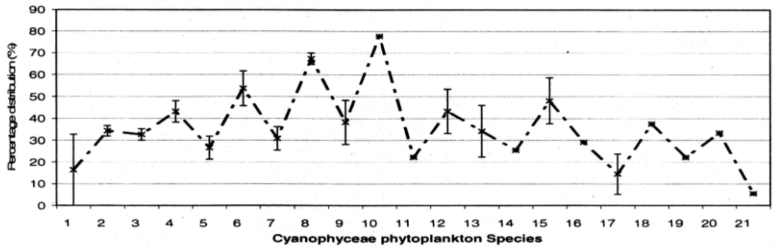


Fig. 4: Checklist and percentage distribution of Cyanophyceae species in Okpoka Creek

(1=*Anabaena sp*, 2=*A. affinis*, 3=*A. arnoldii*, 4=*A.spiroides*, 5= *Anabaenopsis arnoidii*, 6=*Spirulina subsalsa*, 7=*S. laxissima*, 8=*S. major*, 9=*S. princeps*, 10= *Microcystis pulverea*, 11=*Oscillatoria princeps*, 12=*O.lacustris*, 13=*O.tenuis*,14=*O.sp*,15= *Rivularia* sp, 16= *Lyngbya hieronymussi*,17=*L.limnetica*,18=*L.major*,19= *Rivularia curvata*, 20= *Phormidium mucicola* & 21=*N.* sp)

Source: Davies (2008)

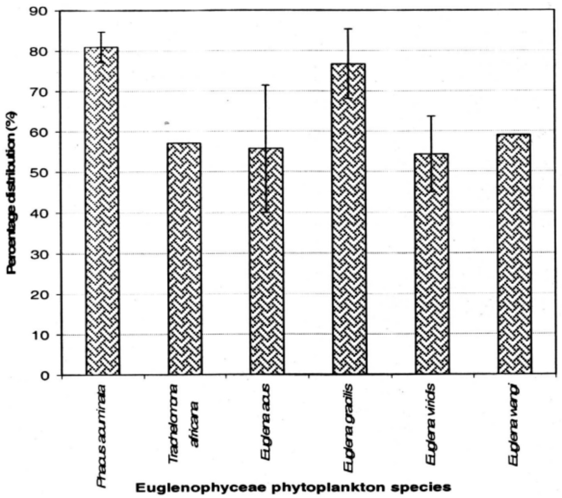


Fig. 5: Checklist and percentage distribution of Euglenophyceae species in Okpoka Creek

Source: Davies (2008)

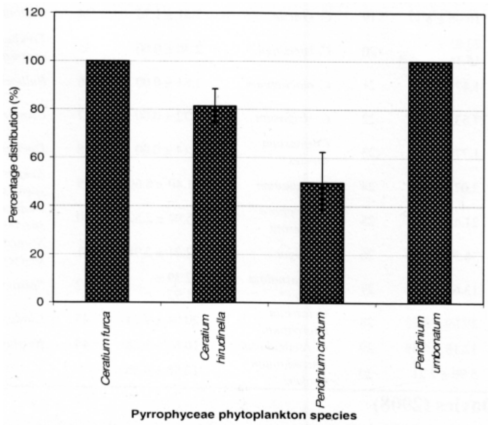


Fig. 6: Checklist and percentage distribution of Pyrrophyceae species in Okpoka Creek
Source: Davies (2008)

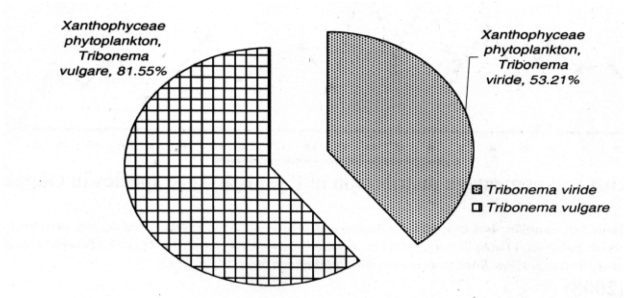


Fig. 7: Checklist and percentage distribution of Xanthophyceae species in Okpoka Creek
Source: Davies (2008)

the metals in the crab *C. guahumi* suggested that the crab can be used as bio-indicator.

5.5.4 Abolude *et al*. (2013) investigated the **heavy metals in water and sediment of Bindare Stream, Chikaji Industrial Area Sabon Gari, Kaduna State, Nigeria. The study detected** the following metals: Aluminium (Al), Titanium (Ti), Iron (Fe), Chromium (Cr), Zinc (Zn), Copper (Cu), Manganese (Mn), Cadmium (Cd) and Nickel (Ni). Metals like Al, Ti, Fe, Zn and Cu showed values above Nigerian Industrial Standards (NIS) (2007). Mn and Cd had no values for comparison. The observed heavy metals had higher concentrations in the sediments than the water signifying the dynamic nature of these heavy metals.

5.5.5 Furthermore, Davies and Abolude (2016) determined the Polycyclic Aromatic Hydrocarbons (PAHs) of surface water from Oburun Lake, Niger Delta, Nigeria. PAHs were detected at all sampling points in the Oburun Lake but were present at very low concentrations for most of them especially the lower molecular PAHs (LMPAHs). The maximum values for Chrysene (1.47 μg/l), Benzo(a)anthracene (1.17 μg/l), Benzo(b)fluoranthene (1.3 μg/l), Benzo(k)fluoranthene (1.22 μg/l), Benzo(a)pyrene (1.33 μg/l), Dibenzo(a,h)anthracene (1.35 μg/l), Indeno(1,2,3-c,d), pyrene (1.17 μg/l) and PAH (Total Detected) (minimum and maximum) (0.49-18.8 μg/l) exceeded the maximum contaminant ***levels*** (MCLs) recommended for aquatic environments, fisheries, aquatic life and drinking water but do not have significant acute toxicity to aquatic organisms. These HMPAHs have great health implications on human and aquatic life. The presence of LMPAHs and HMPAHs in water indicates organic pollution from natural, anthropogenic and biogenic or diagenetic sources.

that the periwinkle, *T. fuscatus var radula*, has a high potential to concentrate heavy metals though the observed concentrations are below WHO limit. The measured physico-chemical parameters (temperature, 28.3-31.5 °C; salinity, 14.5-21.2 ‰; pH, 7.2-7.4; dissolved oxygen, 5.5-7.6 mg/L) varied within the stations.

5.5.2 Davies *et al*. (2007) assessed the trace metals (**Iron, Copper and Zinc**) in periwinkle (*Tympanotonus fuscatus var radula*) from Elechi Creek, Upper Bonny Estuary, Nigeria. The study showed that sediments accumulated most of these heavy metals than the water while the soft tissues concentrated more heavy metals than the shells (P>0.050) in both small and large periwinkles. Generally, the large periwinkles concentrated more heavy metals than the small ones. The pattern of heavy metals in soft tissues and shells was (Fe>Zn>Cu). The BCF revealed that these periwinkles have high potential to concentrate heavy metals in their shells and soft tissues but this decreases with increasing metal concentration in the sediments.

5.5.3 The level of heavy metals in freshwater crab (*Cardisoma guahumi*) obtained from Ahmadu Bello University Reservoir, Zaria, Nigeria was evaluated by Abolude *et al*. (2009a). The data indicated variable levels of some of the metals in the crab samples. Enrichments of some of the metals were higher than others, in some stations and on the different body components. The most concentrated was calcium (46500±16300ppm) while the least concentration was obtained in Niobium (29.3ppm). Correlation coefficient between the various stations and between the various body components shows significant differences (P<0.05). Concentrations of some metals in Ahmadu Bello University Reservoir, Zaria were found to be higher than the WHO recommended safe reference values. The high level of some of

4.3.2 Periphyton of Nigeria

The periphyton assemblage of Okpoka Creek represents the periphyton species composition, diversity, abundance and distribution of the Nigerian inland waters (Fig. 8-13 and Tables 6 and 7). The different taxa are shown below. The periphyton also supports fisheries.

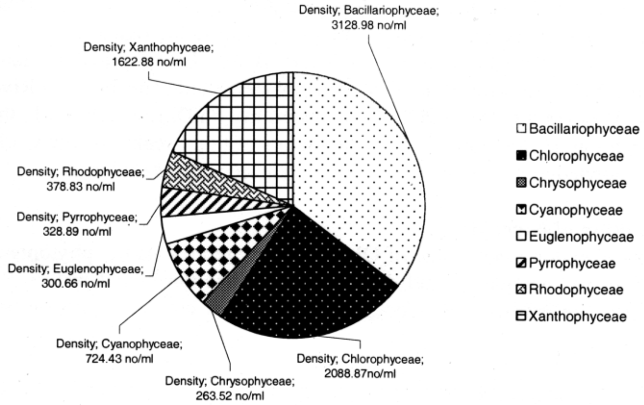


Fig. 8: Epiphyton density in Okpoka Creek

Source: Davies (2008)

Table 6: Checklist and percentage distribution of Bacillariophyceae species in Okpoka Creek

S/No.	Species	Percentage distribution (%)	S/No.	Species	Percentage distribution (%)	S/No.	Species	Percentage distribution (%)
1	*Bacillaria species**	-	20	*N. similis*	1.51 ±0.00	39	*Stenopterobia intermedia*	1.41 ±0.00
2	*Caloneis amphisbaena*	13.96 ± 0.00	21	*N. gastrum*	14.69 ±0.86	40	*Synedra ulna*	16.59 ±2.16
3	*Cyclotella species**	16.57 ± 0.00	22	*N. species**	31.64 ±5.50	41	*S. affinis*	16.52 ± 1.41
4	*C. comta*	9.98 ±1.71	23	*Neidium species**	0.50 ± 0.00	42	*S. acus*	23.32 ± 5.63
5	*C. menephiniana*	11.84 ±2.41	24	*Nitzschia bilobata*	22.26 ±3.03	43	*S. species**	19.68 ± 5.80
6	*C. striata*	9.81 ± 0.00	25	*N. apiculata*	5.47 ± 0.96	44	*Tabellaria species**	0.20 ± 0.00
7	*C. operculata*	12.80 ±0.12	26	*N. lanceolata*	10.75 ± 2.10	45	*T. binalis*	16.07 ± 1.25
8	*C. antiqua*	19.61 ±5.63	27	*N. acuta*	2.51 ± 0.00	46	*Tetracyclus species**	0.20 ± 0.00
9	*C. glomerata*	14.41 ±0.97	28	*N. sigma*	22.76 ±4.79	47	*Melosira varians*	14.40 ± 1.60
10	*Cymbella lata*	3.19 ±0.00	29	*N. linearis*	0.40 ± 0.00	48	*M. listans*	16.14 ±2.85
11	*C. species**	0.50 ±0.00	30	*N. species**	27.17 ± 0.00	49	*M. granulata*	17.66 ± 4.95
12	*Cymatopleura species**	2.51 ± 0.00	31	*Pinnularia horealis*	6.60 ±2.83	50	*Frustulia rhomboides*	23.85 ± 4.50
13	*Gryosigma attenuatum*	5.41 ± 0.00	32	*P. mesolepta*	6.53 ±0.00	51	*Coscinodiscus laaistris*	12.84 ± 6.12
14	*G. acuminatum*	17.51 ± 2.64	33	*P. species**	6.33 ± 0.00	52	*Fragilaria intermedia*	2.36 ± 1.05
15	*G. paradoxa*	11.84 ±0.00	34	*Surirella robusta*	1.65 ±0.46	53	*Amphora ovalis*	3.05 ± 0.41
16	*G. species**	21.99 ±0.00	35	*S. constricta*	0.20 ± 0.00	54	*Cocconeis placentula*	2.62 ± 0.50
17	*Navicula placentula*	13.61 ± 2.24	36	*S. species**	1.31 ± 0.00	55	*Pleurosigma species**	1.31 ± 0.00
18	*N. recognita*	1.51 ± 0.00	37	*Stauroneis parvula*	11.11 ±0.00			
19	*N. pusilla*	19.84 ±0.77	38	*S. species**	33.39 ±16.17			

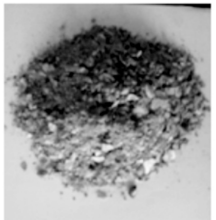
*Undentified   Source: Davies (2008)

5.4.2.3 A study was conducted to evaluate buffering potency of rock shells (*Thais coronata)* on acidic borehole water for aquaculture by Davies *et al*. (2015). pH steadily increased from 4.0 to acceptable range of 6.5-9.0 in all treatments except T1 (control, no treatment) at the end of trials. All shell forms (crushed burnt rock shells, uncrushed burnt rock shells, crushed unburnt rock shells and uncrushed unburnt rock shells) at least 270 g buffered the acidic water but crushed burnt rock shells are preferable to others.

5.3.2.4 The paper, **Davies and Ogidiaka (2017) on b**uffering potency of periwinkle shells (*Tympanotonus fuscatus*) **as alternative buffer to calcium carbonate for fish farming in the Niger Delta, Nigeria documented that all shell forms (**burnt crushed periwinkle shells, burnt uncrushed periwinkle shells, unburnt crushed periwinkle shells and unburnt uncrushed periwinkle shells**) especially** burnt crushed periwinkle shells at 5400 g changed the acidic water (4.0) to alkaline from (6.58).

5.5 Contributions to heavy metal and aromatic hydrocarbons (PAHs) studies

5.5.1 Davies *et al*. (2006c) studied the occurrence of heavy metals (**chromium, Cr; cadmium, Cd and lead, Pb)** in sediment, water and periwinkle (*Tympanotonus fuscatus var radula*) from Elechi Creek, Niger Delta, Nigeria. The results showed that sediments concentrated more heavy metals than the water while the periwinkles accumulated more of these metals than the sediments. Chromium was the highest concentrated heavy metal in both the normal and depurated periwinkles (Cr>Pb>Cd). The biological concentration factor (BCF) that increased with the size of the periwinkles revealed



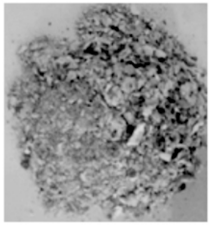



Plate 9a: CBOS **Plate 9b:** UBOS **Plate 9c:** CUOS **Plate 9d:** UUOS

CBOS- Crushed Burnt Oyster Shells; UBOS- Uncrushed Burnt Oyster Shells;
CUOS- Crushed Unburnt Oyster Shells; UUOS- Unrushed Unburnt Oyster Shells

5.4.2.2 Davies and Ogidiaka (2015) research work on different forms of bloody cockle shells (*Anadara senilis)* (crushed burnt bloody cockle shells (CBBS) [T3], uncrushed burnt bloody cockle shells (UBBS) [T4], crushed unburnt bloody cockle shells (CUBS) [T5] and uncrushed unburnt bloody cockle shells (UUBS) [T6]) (Plates 10a-10d) as alternative buffer to calcium carbonate on acidic borehole water for fish farming showed that all shell types performed well as buffering agent especially crushed burnt bloody cockle shells. pH progressively increased from 4.0 to the acceptable range of 6.5-9.0 in all treatments except T1 at the end of study.

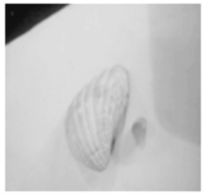



Plate 10a: CBBS **Plate 10b:** UBBS **Plate 10c:** CUBS **Plate 10d:** UUBS

CBBS-Crushed Burnt BloodyCockle Shells; UBBS- Unrushed Burnt BloodyCockle Shells;
CUBS- Crushed Unburnt BloodyCockle Shells; UUBS- Uncrushed Unburnt BloodyCockle Shells

Table 7: Checklist and percentage distribution of *Chlorophyceae* species in Okpoka Creek

S/No.	Species	Percentage distribution (%)	S/No.	Species	Percentage distribution (%)	S/No.	Species	Percentage distribution (%)
1	*Closterium gracile*	6.60 ± 2.51	10	*Netrium digitus*	34.81 ± 6.71	19	*Desmidium grevelli*	2.06 ± 0.00
2	*C. parvulum*	68.14 ± 0.00	11	*Cosmarium species**	0.51 ± 0.00	20	*Scenedesmus species**	0.62 ± 0.00
3	*Crucigenia truncate*	6.25 ± 0.00	12	*Rhizodonium hookeri*	7.84 ± 1.79	21	*Mougeotia species**	1.34 ± 0.00
4	*C. retangularis*	29.32 ± 3.25	13	*R. species**	56.67 ± 0.00	22	*Pithophora species**	7.50 ± 0.00
5	*Gonatozygon aculeatum*	8.37 ± 4.17	14	*Microspora species**	14.87 ± 0.00	23	*Chaetophora elegans*	14.70 ± 3.18
6	*Cladophora glomerata*	6.73 ± 1.06	15	*M. villeana*	69.99 ± 3.81	24	*Oocystis eremasphaena*	12.31 ± 0.42
7	*C. species**	15.91 ± 0.00	16	*Planktosphaeria gelatinosa*	7.69 ± 0.00	25	*Coelastrum recticulatum*	10.45 ± 1.39
8	*Tetraedon regulare*	3.28 ± 1.48	17	*Cyclindrocapsa geminella*	15.46 ± 0.00	26	*C. microporum*	9.42 ± 0.00
9	*Oedogonium crispum*	4.01 ± 1.85	18	*Characium debaryanus*	44.33 ± 0.00			

*Unidentified

Source: Davies (2008)

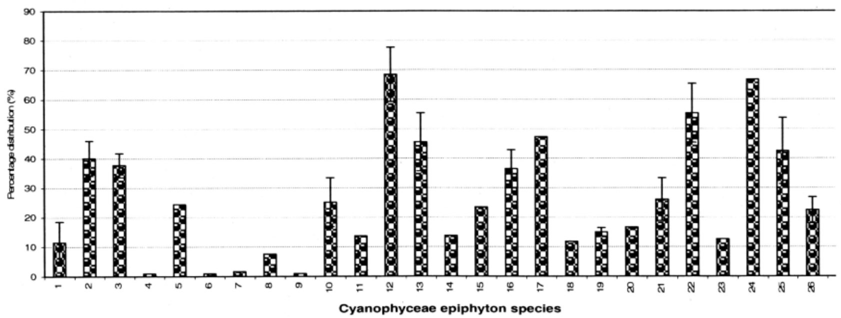


Fig. 9: Checklist and percentage distribution of Cyanophyceae species in Okpoka Creek

1= *Anabaena flos-aquae*, 2=*A.affinis*, 3=*A. spiroides*, 4=*A.sp*, 5=*Anacystis sp*, 6=*Entophysalis sp*, 7=*Phormidium muciola*, 8=*P.valderiae*, 9=*Microcystis sp*, 10=*Anabaenopsis arnoldii*, 11=*Nsp*, 12=*Oscillatoria rubescens*, 13=*O.tenuis*, 14=*O.princeps*, 15=*O.limosa*, 16=*O.lacustris*, 17=*O.sp*, 18= *Trichodesmium distorta*, 19=*Spirulina major*, 20=*S.princeps*, 21=*S.laxissima*, 22=*Rivularia curvata*, 23=*R.mediteranea*, 24=*Trichodesmium lacastre*, 25=*R.sp*, 26=*Lyngbya major* & 27=*L.limtica*)

Source: Davies (2008)

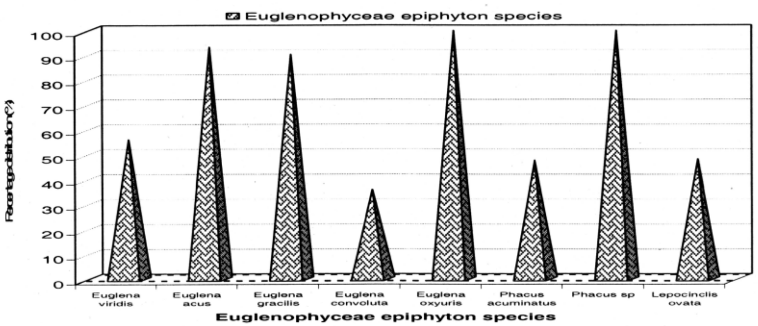


Fig. 10: Checklist and percentage distribution of Euglenophyceae species in Okpoka Creek

Source: Davies (2008)

5.4.1.4 Davies and London (2018) assessed the buffering efficiency of phytoplankton on acidic borehole water for fish production in Port Harcourt, Rivers State. The study revealed 4 litres of green water containing phytoplankton buffered the acidic 10 litre borehole water (pH 4.48) to pH 6.52 within 3 days.

5.4.2. Use of shells of aquatic animals as organic buffers

5.4.2.1 Davies and Ansa (2014) conducted a study to assess buffering efficiency of *Crassostrea gasar* (oyster) shells on acidic borehole water for aquaculture in the Niger Delta, Nigeria. The study identified that **buffering potency of** crushed burnt oyster shells (CBOS), uncrushed burnt oyster shells (UBOS), crushed unburnt oyster shells (CUOS) and uncrushed unburnt oyster shells (UUOS) (Plates 9a-9d) were similar to that **of calcium carbonate (CA) for maximum of four and eight days depending on trial types (first use, first reuse, second reuse or third reuse).** The pH values of all treatments except T1 in the first and second trials were within the range of 6.5-9.0 acceptable for fish production. **Buffering efficiency of** CBOS, UBOS, CUOS and UUOS were similar to that **of CA.** This study recommends use of at least 270 g of CBOS and CUOS for treatment of 100 litres of acidic water for minimum of two days for aquaculture.

5.4.1.3 Assessment of crushed water hyacinth (*Eichhornia crassipes*) (wet whole plant (Plate 8), wet roots, wet stems, wet leaves, dried whole plant, dried roots, dried stems and dried leaves) as organic buffer for fish production in Port Harcourt, Nigeria was carried out by Davies and Jaja (2014b). The study revealed that dried crushed water hyacinth (roots, stalks, leaves and whole plant) increase the pH of acidic water as $CaCO_3$ does (Table 27).

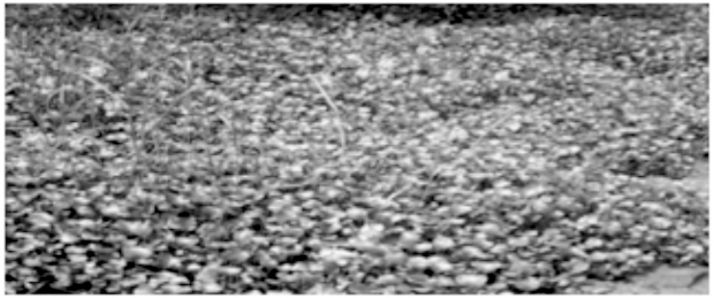


Plate 8: Water hyacinth plant in fish pond

Table 27: pH of water at different treatments

Treatment	pH			
	Minimum	Maximum	Range	Mean ± SEM
C (T1)	3.0	5.0	2.0	4.50±0.13c
WWP (T2)	3.0	6.3	3.3	5.67±0.21b
WR (T3)	3.0	6.7	3.7	5.89±0.22b
WS (T4)	3.0	6.4	3.4	5.66±0.20b
WL (T5)	3.0	6.4	3.4	5.78±0.21b
DWP (T6)	3.0	6.8	3.8	6.05±0.24a
DR (T7)	3.0	6.9	3.9	6.07±0.23a
DS (T8)	3.0	6.9	3.9	6.07±0.23a
DL (T9)	3.0	6.8	3.8	6.10±0.22a
CA (10)	3.0	7.2	4.2	6.24±0.22a

Means with different letters on same column are significantly different ($P<0.05$). WWP- Wet Whole Plant; WR- Wet Roots; WS-Wet Stem; WL-Wet Leaves; DWP-Dried Whole Plants; DR-Dried Roots; DS-Dried Stems; DL-Dried Leaves; CA- Calcium Carbonate

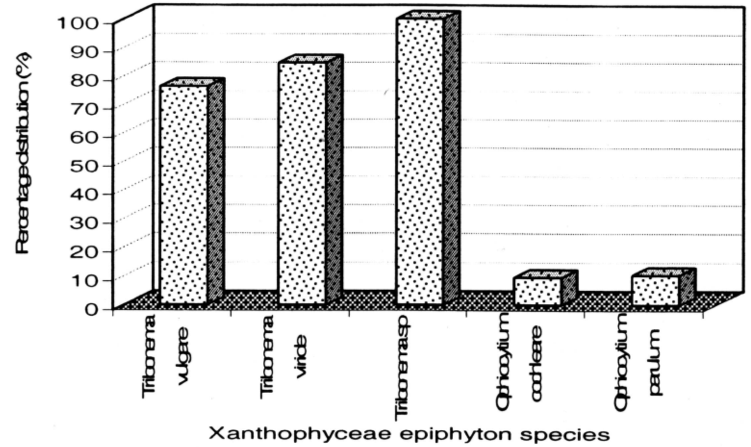


Fig. 11: Checklist and percentage distribution of Xanthophyceae species in Okpoka Creek

Source: Davies (2008)

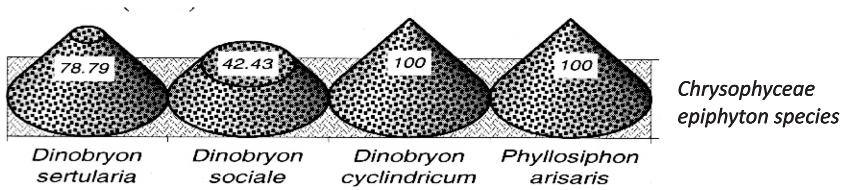


Fig. 12: Checklist and percentage distribution of Chrysophyceae species in Okpoka Creek

Source: Davies (2008)

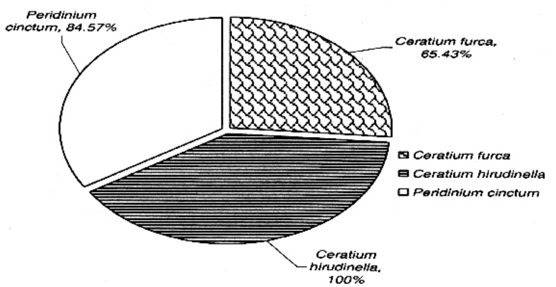


Fig. 13: Checklist and percentage distribution of Pyrrophyceae species in Okpoka Creek

Source: Davies (2008)

4.3.3 Macrophytes of Nigeria

Macrophytes are the larger aquatic plants that grow in or near water. A macrophyte usually dominates in wetlands, littoral zones of shallow lakes and streams. Macrophytes are classified as follows: marginal or emergent (grasses such as *Juncus*, *Cyperus maculatus*, *Typha australis*, *Carex*, *Sarpus* and *Sparganium*), submerged (*Myriophyllum spicatum, Hydrilla verticillata, Ceratophyllum demersum, Potamogeton crispus, Potamogeton pectinatus*), floating (water hyacinth, *Eichhornia crassipes; Salvinia*; duckweed, *Lemna*; water velvet, *Azolla*; *Trapa* and water lettuce, *Pistia stratiotes*), floating-leaved (water lily, *Nymphaea lotus*; pondweed, *Potamogeton*; *Hydrocotyle*) and helophytes. Massive occurrence of these aquatic plants especially floating and submersed plants is a common feature on tropical and subtropical water bodies. Both the floating and submersed aquatic macrophytes can become nuisance plants due to their explosive growth caused by the favourable nutrient environment, and anthropogenic impact through eutrophication of some, especially small water bodies.

of plantain plant competed favourably with the buffering efficiency of $CaCO_3$.

5.4.1.2 Davies and Jaja (2014a) e**valuated the potency of pawpaw (*Carica papaya*) plant parts (**dried leaves, fresh leaves, dried stem and fresh stem) **as organic buffers for fish production in Port Harcourt, Nigeria**. The study **showed that** these forms of pawpaw plant buffer water with low pH as $CaCO_3$ does (Fig. 20 to Fig. 23).

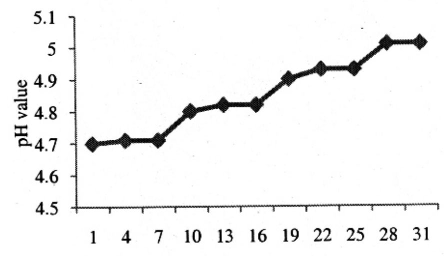


Fig. 20: Daily pH values of experimental water not treated with pawpaw plant parts

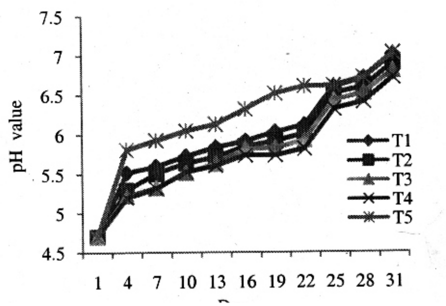


Fig. 21: Daily pH values of experimental water treated with 2.4 g of pawpaw plant parts

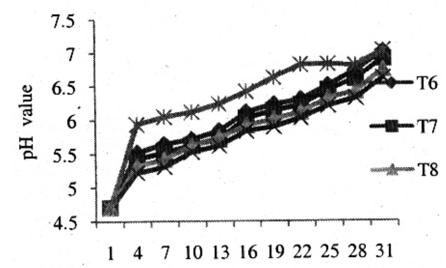


Fig. 22: Daily pH values of experimental water treated with 6 g of pawpaw plant parts

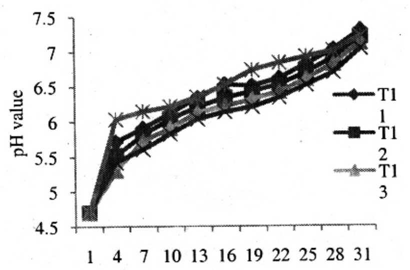


Fig. 23: Daily pH values of experimental water treated with 12 g of pawpaw plant parts

5.4.1 Use of plants as organic buffers

Plants (aquatic and terrestrial) have gained recognition as materials for biotechnology. Water hyacinth has been used for the production of biofuels. Davies and Mohammed (2011) reported the moisture-dependent engineering properties of water hyacinth parts with the view of briquettes (solid iofuels) production. Tiger nut (*Cyperus esculentus*) was used for the production of energy and it has been known as medicinal plant (Abano and Amoah, 2011). Iranian Pistachio has been utilized for biofuels production (Kouchakzadeh and Tavakoli, 2010). Wood vinegars were utilized as sustainable coagulating and anti-fungal agents in the production of natural rubber sheets (Baimark *et al*., 2008).

5.4.1.1 Davies *et al*. (2012a) compared the buffering efficiency of plantain (*Musa acuminata*) plant parts (dried stem, wet stem, dried leaves, wet leaves) and calcium carbonate on pH of acidic borehole water. The buffering efficiency of dried stem (T1) on the low pH groundwater was significantly higher than that of dried leaves (T3) ($P<0.05$) (Table 26). Dried stem and leaves

Table 26: pH of water treated with plantain parts and calcium carbonate

Day	Time	Treatment					
		Borehole (T0)	Dried stem (T1)	Wet stem (T2)	Dried leaf (T3)	Wet leaf (T4)	$CaCO_3$ (T5)
1	M	4.20±0.01a	...	4.20±0.01a	4.20±0.01a	4.20±0.01a	4.20±0.01a
	A	4.20±0.01a	4.20±0.01 a	4.20±0.01a	4.20±0.01a	4.20±0.01a	4.20±0.01a
4	M	4.65±0.02e	5.55±0.02 b	4.68±0.02e	5.35±0.02c	4.73±0.01d	6.10±0.01a
	A	4.68±0.01e	5.68±0.03 b	4.73±0.01e	5.52±0.02c	5.01±0.01d	6.13±0.02a
7	M	4.97±0.01e	6.56±0.01 a	5.13±0.03d	5.84±0.03b	5.30±0.02c	6.61±0.01a
	A	5.01±0.01e	6.60±0.02 a	5.14±0.01d	6.03±0.02b	5.51±0.03c	6.66±0.02a
10	M	5.21±0.03e	6.65±0.03 a	5.37±0.02d	6.01±0.01b	5.62±0.02c	6.87±0.02a
	A	5.26±0.01e	7.53±0.01 a	5.41±0.01d	6.14±0.02b	5.70±0.01c	7.62±0.01a
13	M	5.53±0.02e	6.42±0.02 a	5.59±0.01d	6.23±0.01b	5.76±0.03c	6.91±0.02a
	A	5.59±0.03e	7.65±0.01 a	5.67±0.02d	6.34±0.02b	5.91±0.01c	6.98±0.01a
16	M	5.79±0.02d	6.60±0.01a	5.81±0.01d	6.38±0.01b	6.04±0.01c	7.04±0.03a
	A	5.84±0.01e	7.70±0.02a	5.89±0.01e	6.54±0.02c	6.23±0.01d	7.53±0.02a

Means of same time with different letters on same row are significantly different ($P<0.05$); M=morning, A=afternoon, T=treatment, $CaCO_3$=calcium carbonate

Table 8: Aquatic macrophytes of Nigerian inland waters

Family/species	No. of species	Family/species	No. of species
ALISMATACEAE	7	*A. vallisnerioides*	
Burnatia enneandra		AZOLLACEAE	
Caldesia oligococca		*Azolla Africana*	
C. reniformis		CERATOPHYLLACEAE	1
Limnophyton obtusifolium		*Ceratophyllum demersum*	
L. fluitans		CONVOLVULACEAE	2
Sagittaria (Lophotocarpus) guayanensis		*Ipomoea aquatic*	
Wiesneria schweinfurthii		*I. asarifolia*	
ARACEAE	1	CYPERACEAE	5
Pistia stratiotes		*Cyperus alopecuroides*	
AMARYLIDACEAE	1	*C. articulates*	
Crinum natans		*C. exaltatus*	
APONOGETOMACEAE	2	*C. submicrolepis*	
Aponogeton subconjugatus		*Scirpus cubensis*	
GRAMINAE (POACEAE)	12	*N. maculata*	
Echinochloa colonum		*N. micrantha*	
E. pyramidalis		*N. guineensis*	
E. stagnina		ONAGRACEAE	7
Leersia hexandra		*Jussiaea repens* var. *diffusa* *(=Ludwigia stolonifera)*	
Leptochloa caerulescens		*Ludwigia decurrens*	
Oryza longistaminata		*L. erecta*	
O. perennis		*L. leptocarpa*	
Phragmites karka		*L. suffruticosa*	
Rhytachne triaristata		PARKERIACEAE	1
Sacciolepis Africana		*Ceratopteris cornuta*	
Sorghum arundinaceum		PODOSTEMONACEAE	2
Vossia cuspidate		*Tristicha hypnoides*	
HYDROCHARITACEAE	2	*T. trifaria*	
Ottelia ulvifolia		POLYGONACEAE	3
Vallisneria spiralis		*Polygonum lanigerum*	
LEMNACEAE	3	*P. salicifolium*	
Lemna aequinoctialis		*P. senegalense*	

Table 8: — *contd.*

Family/species	No. of species	Family/species	No. of species
L. perpusilla		PONTEDERIACEAE	
Spirodela polyrrhiza		*Eichhornia crassipes*	
LENTIBULARIACEAE	8	*E. natans*	
Utricularia reflexa (=charoïdea)		*E. diversifolia*	
U. gibba subsp. *Exoleta*		*Heteranthera callifolia*	
U. inflexa var. *inflexa*		POTAMOGETONACEAE	2
U. reflexa (=platyptera)		*Potamogeton octandrus*	
U. rigida		*P. schweinfurthii*	
U. vitellaris		RUBIACEAE	1
U. inflexa var. inflexa (=thonningii)		*Mitragyna inermis*	
U. benjaminiana (=villosula)		SALVINIACEAE	1
MARANTACEAE	1	*Salvinia nymphellula*	
Thalia geniculata		SCROPHULARIACEAE	1
MENYANTHACEAE	1	*Limnophila barteri*	
Nymphoides indica		SPHENOCLEACEAE	1
MIMOSACEA	2	*Sphenoclea zeylanica*	
Mimosa pigra		TRAPACEAE	1
Neptunia oleracea		*Trapa bispinusa*	
NAJADACEAE	1	TYPHACEAE	1
Najas horrid		*Typha australis*	
NYMPHAEACEAE	4	**Total species**	**76**
Nymphaea lotus			

Source: http://www.fao.org/docrep/005/t3660e/T3660E04.htm

4.3.4 Zooplankton of Nigeria

The zooplankton assemblage of Okpoka Creek represents the zooplanktons species composition, diversity, abundance and distribution of the Nigerian inland waters (Fig. 14 to Fig. 19). They support the carnivorous animals in the aquatic animals and thus contribute to fisheries production.

Harcourt city, Nigeria is acidic (Davies, 2008). This is a serious constraint to aqua-culturists. Port Harcourt is a highly industrialized city in the Niger Delta area of Nigeria. There are many oil exploration activities going on in this area. Water quality and quantity vary from place to place and are affected by ecological factors such as soil and air quality. On a whole, ground water is considered more desirable for aquaculture because it has more consistent water quality than surface water, and is less likely to contain pathogens or fish (FishDoc, 2010). However, the ground water (borehole) in Port Harcourt has low pH. This has been a major problem affecting the growth and profitability of aquaculture in Port Harcourt. The use of agricultural lime [Calcite, $CaCO_3$ of dolomite CaMg $(CO_3)_2$] has been the conventional method of buffering water and increasing its pH (Viveen *et al*., 1986).

The use of agricultural lime [calcite, $CaCO_3$ of dolomite CaMg $(CO_3)_2$] has been the conventional method of buffering water and increasing its pH (Boyd, 1981). A buffer is like a chemical cushion that neutralizes acids or bases when added to water. It can be natural (carbon dioxide when dissolved in water forms carbonic acid buffer, minerals such as calcium and magnesium which comes from rocks like limestone) or manmade (Clean Water Team [CWT), 2004). pH can change because of external inputs, a large change in temperature and a change in human activity affecting the stream. A difference in pH along a stream can be recorded due to a change in tree type, for example, confer needles are acidic and maple leaves are basic (CWT, 2004). A change in stream bottom material, for example, gravel vs silt vs bedrock.

Low water pH has been a major problem affecting the growth and profitability of aquaculture in Port Harcourt, Nigeria. In recent times, organic agriculture is being advocated for safe and healthy food thus alternative buffer agent is necessary to combat this challenge in order to boost fish production.

to over 50 million tonnes in 2006. The growing importance of the aquaculture sector at the same time also implies an ever increasing responsibility and accountability to produce safe and healthy products in a sustainable way including in terms of economic feasibility, environmental integrity and social responsibility. Plants (aquatic and terrestrial) have gained recognition as materials for biotechnology. Biotechnology is a growing technology in recent times. United Nations (2013) defined it as any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use. It is also the use of living systems and organisms to develop or make useful products.

Water pH is a critical water quality parameter for fish culture. Water quality is one of the most critical factors besides good feed/feeding in fish production (hatchery operation and management, nursery, grow-out and brood stock management). Deterioration in the quality of water increases stress on the captive animals, reduces their growth, makes them vulnerable to disease and cause heavy mortality. Based on this, understanding the physico-chemical qualities of water is critical to successful aquaculture. To great extent, water determines the success or failure of an aquaculture operation. Managing water quality is important but expense (**Davies *et al.*, 2012a**). The quantity of hydrogen ions (H^+) in water will determine if it is acidic or basic. The acceptable range for fish culture is normally between pH 6.5 and 9.0 (FishDoc, 2010. High acidity or alkalinity can cause direct physical damage to skin, gills and eyes. Prolonged exposure to sub-lethal pH level can cause stress, increase mucus production and encourage epithelial hyperplasia with sometimes fatal consequences. Extreme water pH can influence and affect blood pH of fish, resulting in either acidosis or alkalosis of the blood. Total alkalinity and pH interact and can have profound effects on pond productivity, level of stress, fish health, oxygen availability and toxicity of ammonia as well as that of certain metals (FishDoc, 2010). Generally, the pH of water in Port

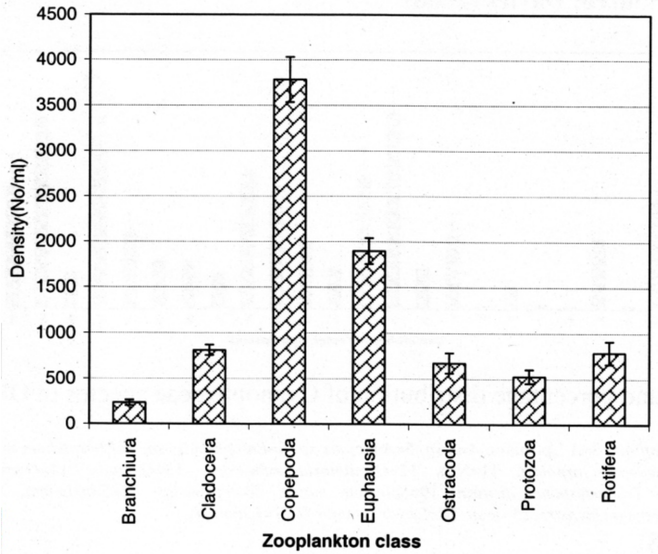


Fig. 14: Density of zooplankton in Okpoka Creek

Source: Davies (2008)

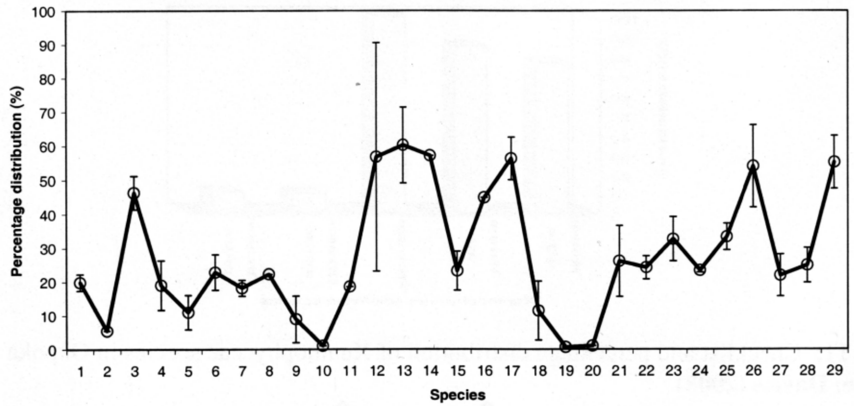


Fig. 15: Percentage distribution of rotifer species of Okpoka Creek

Source: Davies (2008)

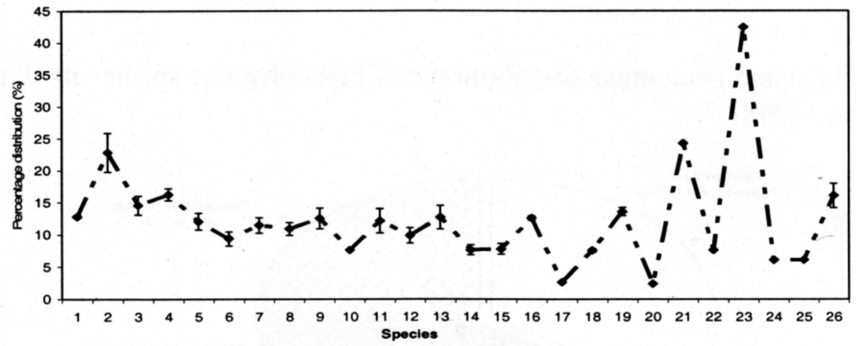


Fig. 16: Percentage distribution of copepod species in Okpoka Creek

(1=*Mesocyclops leukarti;2=Temora longicornis;3=Anomalocera patersoni;4=Centropages typicus; 5=Metridia lucens;6=Oithona similis;7=Pseudocanus elongatus;8=Candacia armata; 9=Acartia loniremis;10=Acartia sp;11=Onchocamptus sp;12=Paracyclops affinis; 13=Paracyclops fimbriatus;14=Calanus sp;15=Macrocyclops distinctus;16=Schmackeria inopinus; 17=Onchocamptus mohammed;18=Eurytemora hirundoides;19=Acanthocyclops bicuspidatus; 20=Pareachaeta norvegica;21=Candacia sp;22=Microcalanus sp;23=Paracalanus sp; 24=Parapontella sp;25=Temora sp;and 26=Cyclops strenus*)

Source: Davies (2008)

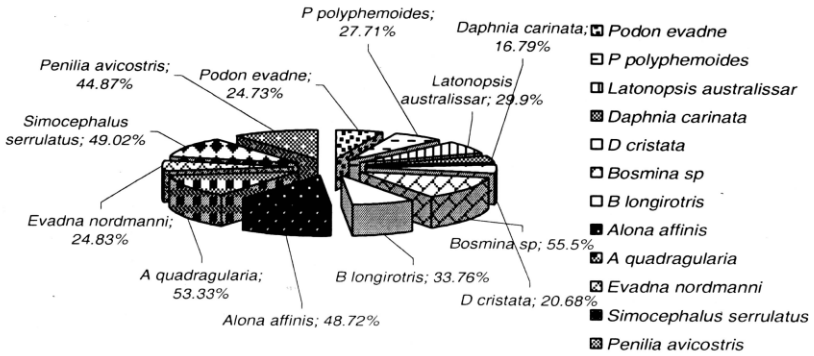


Fig. 17: Percentage distribution of cladocera species in Okpoka Creek
Source: Davies (2008)

Plate 6: ARAC Tidal Earthen Pond

Plate 7: Roone Fish Farm Stagnant Concrete tank

5.3.6 The study of physico-chemical parameters in earthen fish ponds in five local government areas in Bayelsa State, Nigeria by Keremah *et al*. (2014) observed that variations in the measured parameters at the different sampling stations. Temperature ranged from 24.9±0.3 °C-25.3±0.30 °C, pH 6.24±0.02-6.68±0.10 and ammonia-nitrogen (NH_3-N), 0.34±0.20 mg/L-0.55±0.20 mg/L. Dissolved oxygen values were 2.8±0.20 mgL-6.6±0.18 mg/L, biological oxygen demand ranged between 2.9±0.60 and 4.52±0.90 mg/L and total alkalinity as 43.1±18.0 mg/L-93.70±46.53 mg/L. Total dissolved solids varied from 27.9±4.7 mg/L-145.40±91.01 mg/L while total hardness was 19.7±4.1 mg/L-44.3±15.07 mg/L and turbidity as 20.6±3.2 NTU-45.1±15.07 NTU. Electrical conductivity was from 117.3±91.01-378.4±130.2 µmhos/cm. The values for NH_3-N were higher than accepted values for fish culture while those of other parameters favoured good fish production.

5.4 Contributions to organic aquaculture (organic buffers)

In recent times organic aquaculture is being advocated for safe and healthy food. Organic aquaculture is an attempt to mitigate some of the harmful effects of chemicals in a sustainable way. Aquaculture has grown rapidly over the years, from less the one million tonnes in

5.3.4 Davies *et al*. (2008c) determined the growth response of *Clarias gariepinus* fry fed different levels of compounded protein feeds. The study indicated that *C. gariepinus* fry require at least 40% crude protein in their diets for optimum growth. Survival rate may be increased with increase feeding frequencies and rate. Temperature (26.8-27-5 °C), pH (7.23-7.63) and dissolved oxygen (7.77-8.37 mg/L) were not significantly different (P>0.05) in the diet treatments and within the permissible limits for aquaculture.

5.3.5 A study was carried out to determine groundnut cake as alternative protein source in the diet of C*larias gariepinus* fry by Davies and Ezenwa (2010). That study suggested that groundnut cake supplemented with at least 0.45 kg each of lysine and methionine per 100kg of feed for fish feed. GNC diets did not affect water quality parameters: temperature, pH and dissolved oxygen except ammonia were within the acceptable ranges for fish culture.

5.3.5 Davies and Ansa (2010) compared the water quality parameters of freshwater tidal earthen ponds (TEP) (Plate 6) and stagnant concrete tanks (SCT) (Plate 7) for fish production in Port Harcourt, Nigeria. Total alkalinity was significantly higher in the SCT (68.33±10.43mg /l) than in the TEP (30.50±7.4lmg/l). There were no significant differences in the values of temperature, turbidity, pH, salinity, electrical conductivity (EC), dissolved oxygen (DO) and biological oxygen demand (BOD). The values of ammonia (0.90±0.19mg/l) and phosphates (0.33±0.13mg/l) in SCT were significantly higher than those of TEP (0.48±0.16 mg/L and 0.33±0.60 mg/L) respectively. The water quality parameters of the two culture media were similar except for alkalinity, ammonia, phosphate and sulphate. The values of ammonia exceeded the permissible limit of FEPA less than 0.01 mg/L.

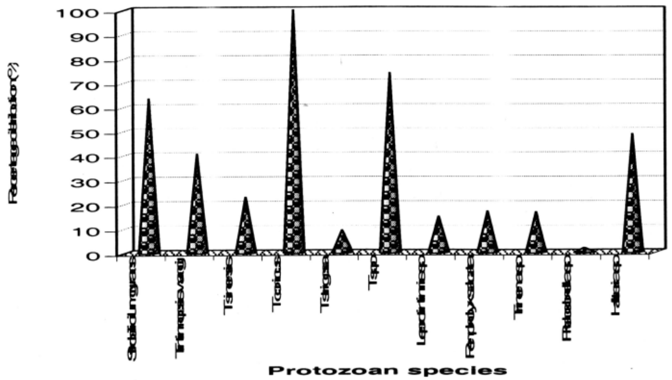


Fig. 18: Percentage distribution of protozoa species in Okpoka Creek
Source: Davies (2008)

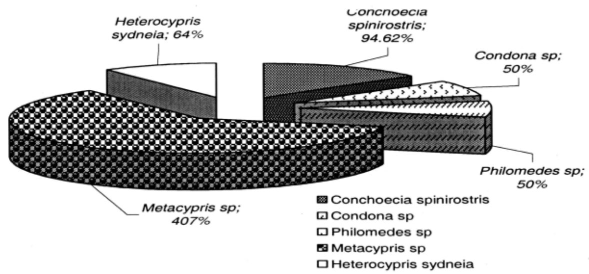


Fig. 19: Percentage distribution of ostracoda species in Okpoka Creek
Source: Davies (2008)

4.3.5 Vertebrates of Nigeria

The (excluding birds) associated with freshwaters of Nigeria are shown in Table 9 and Table 10 reveals the aquatic birds.

Table 9: A preliminary list of vertebrates (excluding birds) associated with freshwaters of Nigeria

	Species	Common name	Habitat		
			Rivers	Lakes	Ponds
REPTILES	*Kinixys bellina*	Water turtle	+++	±	±
Chelonia:	*Pelaneadusa subrufa*	Terrapin	+++	±	±
	Amyda tringuis	Water turtle	+++	±	±
	Pelusios adansoni	Gabon terrapin			
Crocodilia:	*Crocodylus niloticus*	Nile crocodile	+++	±	-
	C. cataphractus	Long nosed crocodile	±	-	-
	Osteolaemus tetraspis	Short nosed crocodile	±	-	-
Squamata:	*Varanus niloticus*	Nile monitor lizard	±	±	±
	V. exanthematicus	Short monitor lizard	±	±	±
	Alligator sp	Alligator			
	Python regius	Royal python	±	±	-
	Python sebae	Rock python	±	±	-
MAMMALS	*Aonyx capensis*	Otter	-	±	-
Carnivora:	*Potamogale velox*	Otter shrew	±	±	±
	Atilax paludinosus	Marsh mongoose	±	±	-
	Genetta sp.	Genets	±	±	-
Sirenia:	Trichechus senegalensis	Manatee	±	++	-
Artiodactyla:	Hippopotamus amphibius	Hippopotamus	±	++	-
	Choeropsis liberiensis	Pigmy hippo	±	-	-
	Tragelaphus spekai	Sitatunga	±	+	-
AMPHIBIA	*Rana galamensis*	Frog	+++	±	±
Frogs:	*R. occipitalis*	Frog	+++	±	±
	R. albolabris	Frog	+++	+++	±
	Xenopus tropicalis	Frog	+++	++	±
	Phrynobatrachus albolabris	Frog	±	++	±
	Ptyhaena moscareniensis	Frog	±	++	±
	Cardioglossa pulchra	Frog	±	++	±
Toads:	*Bufo regularis*	Toad	++	++	++++
	B. maculates	Toad	±	±	++++

* Not indigenous, available in zoos; ** Over 57 species reported in Nigeria and the West African Coast; ++++ more than 100/ha;+++ 50–100/ha;++ 10–50/ha;+ 1–10/ha, do not normally occur in such habitat.

Source: http://www.fao.org/docrep/005/t3660e/T3660E05.htm

Table 25: Abundance, number of species, diversity and percentage distribution of species induced by agrolyser and NPK fertilizers

Parameter	Phytoplankton family	Tank (treatment)				Total	% Total phytoplankton
		A*	B	C	D		
Abundance	Bacillariophyceae (Diatoms)	10	13	37	22	82	6.59
	Cyanophyceae (Blue-green algae)	91	325	498	30	944	75.88
	Englenophyceae (Euglenophytes)	31	75	108	4	218	17.52
	Total	**132**	**413**	**643**	**56**	**1244**	
Number of Species	**Bacillariophyceae**	3	4	5	5	17	
	Achnathes ventricosa						
	Cymbella amphioxys						
	Cymbella ventricosa						
	Eunotia *lunaris*						
	Navicula contenta						
	Cyanophyceae	6	7	9	6	28	
	Anabaenopsis sp						
	Dacfyl cocoopsis						
	Microcystis aearogbinosa						
	Oscillatoria chahbae						
	O. *terebriformis*						
	O. amphibian						
	Ph. Uharinatom						
	Ph. Molie						
	Lyngbya sp						
	Englenophyceae	3	6	4	1	14	
	Trachalomonas ovenburgica						
	T. hispida						
	Strombomonas vernicosa						
	Euglena acus						
	Phacus sp						
	Strombomonas vernicosa						
Diversity	Bacillariophyceae	0.28	0.42	0.56	0.56		
	Cyanophyceae	0.70	0.84	1.12	0.70		
	Englenophyceae	0.28	0.70	0.42	0.00		
Percentage distribution of species (%)	Bacillariophyceae	60	80	100	100		
	Cyanophyceae	66.7	77.8	100	66.7		
	Englenophyceae		55.9	859	88.9	61.1	

A, 0.27 g Agrolyser; B, 200 g NPK; C, 200 g Agrolyser + 0.27 g NPK; D, control

5.3.2 The paper, Davies *et al*. (2006a) investigated the growth response and survival of *Heterobranchus longifilis* fingerlings fed at different feeding frequencies (treatments) and revealed that *H. longifilis* fingerlings should be fed twice daily for higher growth performance. The growth parameters except relative growth rate were significantly different for fishes receiving the different treatments. Survival was not significantly different among treatments. The pH (7.2-7.3), dissolved oxygen (2.90-4.00 mg/L) and temperature (25.8-29.0°C) varied among the treatments.

5.3.3 Davies *et al*. (2006b) examined the i**nduced growth of phytoplankton using two fertilizers (NPK and agrolyser) under laboratory conditions. The** use of agrolyser (micronutrient fertilizer) with NPK (macronutrient fertilizer) increased the phytoplankton population (Table 25) by providing more nutrients. Both types of fertilizers are recommended for use in ponds especially those that are used for raising herbivorous fishes, and to achieve maximum plankton production in the ponds for maximum fish production and hence high profitability. The measured physico-chemical parameters (temperature, pH, turbidity and transparency) varied within the treatments and were within the acceptable ranges for fish production.

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Table 10: Distribution of aquatic bird families in Nigeria and their status

			Habitat		Status				
Family	**Genera**	**Species**	**Aquatic**	**Marine**	RB	R(B)	PM	AM	Other
Podicipepididae	1	1	1	-	1	-	-	-	-
Procellariidae	1	1	-	1	-	-	-	-	1
Hydrobatidae	1	1	-	1	-	-	-	-	1
Pelecanidae	1	2	2	-	2	-	-	-	-
Sulidae	1	2	2	-	-	-	-	-	2
Phalacrocoracidae	1	2	2	-	2	-	-	-	-
Anhingidae	1	1	1	-	1	-	-	-	-
Ardeidae	8	19	18	-	13	3	6	2	1
Scopidae	1	1	1	-	1	-	-	-	-
Ciconiidae	5	8	8	-	1	1	2	4	?
Threskiornithidae	4	6	6	-	3	1	2	-	-
Phoenicopteridae	1	1	1	-	-	-	-	-	1
Anatidae	10	24	24	-	8	3	10	-	2
Pandionidae	1	1	1	-	-	-	1	-	?
Accipitridae	27	47	1	-	27	9	9	2	-
Rallidae	9	16	6	-	8	2	3	-	3
Heliornithidae	1	1	1	-	1	-	-	-	-
Otididae	3	6	-	-	3	1	-	1	1
Jacanidae	2	2	2	-	1	1	-	-	-
Rostratulidae	1	1	1	-	1	-	-	-	-
Haematopodidae	1	1	-	1	-	-	1	-	-
Recurvirostridae	2	2	2	-	-	1	2	-	-
Burhinidae	1	4	1	-	2	1	1	-	-
Glareolidae	3	7	5	-	6	-	1	-	-
Charadriidae	3	19	17	-	9	-	?	?	-
Scolopacidae	9	26	24	2	-	-	25	1	-
Stercorariidae	1	4	-	4	-	-	4	-	-
Laridae	3	23	3	20	1	1	14	2	5
Rhynchopidae	1	1	1	-	1	-	-	-	-
Strigidae	6	12	2	-	9	2	2	-	-
Caprimulgidae	2	10	-	-	5	-	1	8	-
Apodidae	3	13	-	-	3	3	3	-	4
Coliidae	1	2	-	-	2	-	-	-	-
Trogonidae	1	2	-	-	-	2	-	-	-
Alcedinidae	4	12	3	-	9	3	-	-	-
Hirundinidae	4	21	4	-	13	2	3	1	2
Sylviidae	20	72	9	-	30	19	24	-	-
Muscicapidae	7	20	2	-	10	6	3	-	1
Total species	**394**								

RB = Resident breeding; R(B) = Resident, breeding not proved; PM = Palaearctic migrant; AM = All intra-African migrants

Source: http://www.fao.org/docrep/005/t3660e/T3660E05.htm

4.4 Physical, chemical and biological properties of aquatic environments

The aquatic environment can be regarded as a sink; it receives domestic and anthropogenic effluents from its surroundings (land and air).The physical, chemical and biological properties are dynamic or fluctuating and are used to measure the water quality of aquatic environments (**Davies *et al*.**, 2008a; **Davies,** 2014). Water quality refers to the condition or degree of the environmental health of a water body or resource. It is defined as the standard of purity that is necessary for the protection of non-finfish (plants), finfish, shellfish and wildlife populations in the aquatic environments, and for recreational uses in and on the water. Water quality criteria are levels of physical, chemical and biological parameters that are required or needed to meet beneficial uses (such as drinking water, bathing, laundry, cleaning, cooking, recreational use (swimming, ecotourism), and support of aquatic life. There are many physical, chemical and biological properties but only some are presented in this inaugural lecture.

4.4.1 Physical properties

The physical parameters of water are very vital for the life all aquatic organisms (**Davies**, 2014). They are temperature, turbidity, transparency, density, tides to mention but a few.

4.4.1.1 Temperature

Temperature is a measure of the intensity of heat stored in a volume of water with the SI Unit presented in degree Celsius (°C) or Fahrenheit (F). Water temperature is a function of the geographical location and meteorological conditions such as rainfall, humidity, cloud cover, wind velocity amongst others. It is one of the most important physical factors affecting the distribution of life and other physical and chemical parameters in inland waters

economically active range (30-39 years, 34%), which favoured fish farming or fishing development. The source of fund for majority of the fishers was personal investment and this is militating against the output of fishers in Igbedi Creek.

5.3 Contributions to fish production through Aquaculture

The physical, chemical and biological properties of the artificial aquatic environments are also dynamic. My research works on aquaculture documented the various changes in these environments. The first published paper on aquaculture was my M.Sc. Research Work, spanned between the Fish Farm and Research Laboratory.

5.3.1 The article, Ugwumba, Ugwumba, Sowunmi, **Bubu** and Ofuani (1995) on induced ovulation, artificial spawning, survival rate and early growth of larvae of the African Catfish, *Clarias gariepinus* documented the dynamic of biological and physico-chemical properties of artificial aquatic environments. The amount of ovaprim (artificial reproductive hormone) administered was between 0.3 and 0.4 ml for females weighing 280-600 g and 0.15 and 0.45 ml for males weighing 670-1,800 g. Latency period was 13.45-16 h and incubation period ranged from 24-36 h at temperatures of 25-27 °C and pH, 7-8. Fecundity estimates ranged between 14,000 for a 320 g fish to 56,000 in a 480 g fish. A 600 g fish had a fecundity estimate of 39,960 eggs. The pseudogonado-somatic index (GSI) used as index of sensitivity ranged from 6.66-40.00% and smaller fishes had higher values. Larval production was 69.1%, 70% and 71% of the fertilized eggs in the three trials and up to 69.32%, 67.5% and 65.2% of the hatchlings survived while about 30.7%, 32.5% and 37.7% were deformed and died for the duration of the 14 days trials. A four times feeding regime for the larvae produced specific growth rates of 0.9-1.8% on a feed conversion ratio of 2.32-4.34.

fishers (98.89%) used crafts such as paddles and canoes while 1.11% used outboard engines. Commonest gear used included traps (45.56%) hook and longline (5.56%). The most pressing constraints faced by fishers include lack of potable water, epileptic power supply and no good markets. Therefore, basic social infrastructures should be provided for the artisanal fishing communities in order to promote their social lives, welfare, standard of living and the capacity to have sustainable fishing activities in the interest of food security and poverty alleviation.

5.2.1.5 Davies *et al*. (2013a) studied the **length–weight relationship, condition factor and sex ratio of *Clarias gariepinus* juveniles reared in concrete tanks.** *C. gariepinus* juveniles cultured in concrete tanks exhibited positive allometric growth (b values above 3). This growth pattern favours fish farming as it enhances its profitability. Weight of fish and not the length determines the selling price of fish as fishes are sold by weight. The fish specimens were in good health condition based on the observed condition factor (>1). The recorded sex ratio favours broodstock development and hatchery development. The observed water quality parameters were within the acceptable range for fish production hence the observed growth pattern and condition factor.

5.2.1.6 The survey of fishing gear and status of fishers in Igbedi Creek, Nigeria Delta, Nigeria was investigated by Kwen *et al*. (2013b). The study revealed three major types of fishing gear being used in Igbedi Creek namely hook and line, trap and net. The most common fishing gear being used is the net which comprises gillnets, drift nets, seine nets and cast nets. Majority of the fishers' age range was within the agile

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thus it is called the master factor (Davies, 2014). Temperature controls the rate at which organisms metabolize or break down food items into assimilable nutrients that they can use. Exchange of gases, such as oxygen (O_2) and carbon dioxide (CO_2), in the aquatic environments is also greatly affected by temperature. Metabolic rate increases 2 or 3 fold for every 10 °C increase in temperature. Temperatures also affect the survival of organisms as they develop/evolve through various life cycle stages, such as egg, larval, and juvenile stages. It affects the rate of development, timing and success of reproduction, mobility, migration patterns and sensitivity of organisms to toxins, parasites and diseases effect. The life cycle of organisms are affected by changes in temperature. Temperature affects the rate of chemical reactions and increases evaporation and volatilization of dissolved substances. The metabolic rate of estuarine organisms is related to temperature so that in warm waters, respiration rates increase leading to increased rates of oxygen consumption and decomposition of organic matter. Growth rates of bacteria and phytoplankton increase in warmer temperatures, and can contribute to increased water turbidity, macrophytic growth and algal blooms.

4.4.1.2 Turbidity

Turbidity is a description of how clear water is, or the clarity of the water and it is a popular indicator of sediment load. It is an important variable that generally ranges from 1 to 1000 NTU (Nephelometric Turbidity Units). Sources of turbidity in water bodies are natural and anthropogenic. Natural sources are phytoplankton (a major source of turbidity in an aquatic ecosystem), clay, silts from shorelines erosion, sediment loading, suspended soil particles, resuspension bed sediments and organic detritus from streams (**Davies**, 2014). Anthropogenic origins of turbidity are effluents containing sewage, dye or coloured materials, suspended solids from industries and domestic sources.

Turbidity is generally high during the rainy season and low during the dry season due to less natural erosion and runoff. Turbidity affects aquatic biological communities. High turbidity reduces photosynthesis of submerged, rooted aquatic vegetation and algae which result in reduction of plant growth and in turn suppress fish productivity by reducing available dissolved oxygen (**Davies**, 2014). Turbidity by plankton is not harmful to fish when at moderate level and it makes it easier to catch fish as they are less wary. It also affects recreational uses of water. Turbidities in natural water systems seldom exceed 20,000 mg/L and even muddy waters usually have less than 2,000 mg/L (Boyd, 1981). High turbidity adversely affects domestic and industrial uses of water. The level can be increased or elevated by the presence of organic matter, effluents, or run-off with high concentrations of suspended solids. Turbidity is highly variable on a temporal scale, with seasonal changes occurring due to biological activity and surface run-off. Heavy rainfall can also result in hourly variations in turbidity.

4.4.1.3 Transparency

Transparency is inversely proportional to turbidity, that is, it has negative correlation with turbidity (**Davies**, 2014). It is the amount of light that penetrate the surface of the aquatic environment. A Secchi disk is used to

trapping. The Malian trap is more efficient than the Ikara trap in terms of catch, quantity of fish catch and in the capture of the family Mochokidae. This study therefore suggests the use of the Malian trap for fisheries management.

5.2.1.3 The study of Davies and Okadi (2012) on **condition factor and length-weight relationship of *Liza falcipinnis* (Linnaeus, 1758) from Elechi Creek, Niger Delta, Nigeria documented** a total of 1,597 mullets, 979 (females) and 618 (males) with sizes ranging from 9 to 28cm; 12g to 71.8g (females) and 8 to 24cm; 11.6 to 56.9g (males). The mean monthly condition factor (K) ranged between 0.768 and 0.995 with mean = 0.8635±0.0463. The regression equation derived from length-weight relationship (LWR) for the species were LogW=-0.5644+1.8618TL; r=0.8236; b=1.8618 (females), LogW=-0.5747+1.6990LogL; r=0.9354; b=1.6990 (males) and LogW=-0.8763+1.9669LogTL, r=0.9470; b=1.9669 (combined sex). *L. falcipinnis* has negative allometric growth and is in good condition. It is recommended that the present level of exploitation should be maintained; closed season and gear restriction should be observed.

5.2.1.4 Davies and Kwen (2013a) evaluated the **status and constraints of artisanal fishers in the lower Taylor Creek area, Niger Delta, Nigeria. That study revealed** that 42.22% of the fishers were within the active age range of 31–40 years while 4.44% were within the non-active age range (51 – 60 years). Male fishers recorded 72.22% while 27.78% were females. The survey showed that 30.00% had no formal education indicating that the level of illiteracy is high among the fishers while 3.33% had tertiary education. Most of the

Fishing gear can be described as any kind of equipment used in harvesting, cropping or capturing fish from any water body. Trapping is a passive way to catch fish, shellfish, crustaceans (crabs, prawns, etc.) and cephalopods (octopus, squid, etc.) and it is different from active fishing methods such as dredging and trawling (**Kwen *et al*., 2013b).** Traps are small or large structures fixed to the shore and are simple passive fishing gear that allows fish to enter and then make it hard for them (fishes) to escape. This is often achieved by putting chambers or valves in the trap that can be closed once the fish enters, having a funnel that make it difficult for the fish to escape.

5.2.1.1 Davies (2009) investigated the **finfish assemblage of the lower reaches of *Okpoka* Creek, Niger Delta, Nigeria.** A total of 11 species from 8 families of finfishes dominated by *Sardinella maderensis* (47.33%) were observed. Seasonal catches of finfishes were not significant ($p>0.05$). The highest relative abundance was recorded in March (18.18%) and the lowest in April (9.09%). The low finfish species diversity indicates that finfish population is over-fished by the local fishers and constant dredging activities have degraded the environment. It is therefore recommended that there should be closed fishing season, selective fishing gear should be used and dredging should be controlled.

5.2.1.2 The article, Davies and Kwen (2012) on **fish assemblages of selected traditional fishing traps (Malian and Ikara) in the Upper Nun River, Niger Delta, Nigeria** revealed the presence of 31 species in 13 families. The two traps demonstrated the ability to trap fish species of different types of habits and habitats and also showed close ties in their effectiveness in fish

estimate transparency in metres. The average of the depths of disappearance and appearance of the Secchi disk is measured as the Secchi disc transparency of the water.

4.4.1.4 Density

Density is the ratio of mass of water to volume of water. It varies with salinity and temperature. Oceanic waters with higher salinities are denser than fresh waters with lower salinities. Also, waters that have cooler temperatures have higher densities than waters with warmer temperatures.

4.4.1.5 Tides

Tides are the periodic rise and fall of the ocean's surface. They are caused by the gravitational pull of the moon and the sun on the earth. The moon is much closer to the earth than the sun so its gravitational pull on the earth is much greater than that of the sun. The moon's gravitational attraction “pulls” the ocean covering the earth's surface toward the moon, creating a bulge of water at the point on the earth directly facing the moon. There are different types of tides. **High tide** is sometimes called **flood tide**. **Low tide** is referred to as **ebb tide**, and **slack tide** is the time just before the tide turns during which there is little tidal water movement. Flood and ebb tides may also be referred to as rising or falling tides, respectively. Tidal levels are also referred to as high or low, in or out, and up or down. A tidal cycle is the complete cycling from one low tide to the next low tide and it is generally half a day in length. Tidal periods are the times from low tide to high tide, and are generally six hours in length. High and low tides do not occur at the same time every day. They happened approximately 50 minutes later each day.

Tides have a major effect on the circulation of materials (dissolved and suspended) within an estuary. Tidal movement will not only be visible in currents but can be identified by changes in water quality variables such as salinity, dissolved oxygen, biological oxygen demand, turbidity and pH (**Davies,** 2014). Currents reach maximum velocities at mid-tide and a minimum of zero near tide change. This affects the suspension and resuspension of sediments and pelagic organisms.

4.4.2 Chemical parameters

4.4.2.1 pH (Hydrogen ion concentration/power of hydrogen)

pH is an index of the hydrogen ion concentration and a very important environmental variable (**Davies**, 2014) . Surface water usually tends to be alkaline while ground waters are more acidic. The range of pH is broader in freshwater than in seawater; seawater ranges from 8.0 to 8.3. The pH of the water may affect the species composition of an aquatic environment, the bioavailability of nutrients including trace elements and their relative toxicity. Discharges should not alter the ambient pH by more than 0.5 pH units in the mixing zones for the protection of the aquatic environment. California State Water Resources Control Board (SWRCB) (2004) stated that changes in normal pH shall not exceed 0.2 units for waters with marine or saline beneficial uses, 0.5 units for freshwaters supporting coldwater or warmwater fisheries. Boyd (1981) recommended pH 6.5-9.0 as optimum for fish production and a pH below or above this level is not desirable for this purpose. Marked changes in pH over time can signify the presence of effluents and atmospheric deposition of acid-forming substances. However, diel variation in pH also occurs

5.1.5.2 The article, Davies and Tawari (2010) on season and tide effects on sediment characteristics of Trans-Okpoka Creek, Upper Bonny Estuary, Nigeria revealed that sand was significantly higher at dry season (72.06 ± 1.49%) and high tide (72.43±2.02%) than at wet season (66.73 ±1.36%) and low tide (68.38±1.18%)($P<0.05$). However, clay was significantly higher at wet season (21.27±0.90%) and low tide (19.32 ±0.76%) than at dry season (15.02 ±0.90%) and high tide (14.60±1.26%) ($P<0.05$).

5.1.5.3 The study of Davies and Tawari (2013) on **spatial and temporal variations of physico-chemical characteristics of sediment of Okpoka Creek, Nigeria elucidated** that the sediment from Okpoka Creek is acidic and sandy-loam consisting of sand, silt and clay. The sediment values; pH and total hydrocarbon were low and varied with station and year. The sediment organic matter, organic carbon and conductivity were high and also varied with station and year. Sediment conductivity is characteristic of coastal waters. It can be concluded that Okpoka Creek is under stress due to high TOC and TOM) and low sediment pH.

5.2 Contributions to Fisheries (Fisheries Biology and Management)

My studies on Fisheries Biology and Management revealed their changing nature in the inland waters.

5.2.1 Studies On Finfish And Shellfishes

Fishing is one of the oldest ways by which people have fed themselves and their families and primitive trapping is probably the oldest form of fishing Davies and Kwen (2012).

(0.54±0.19 mg/L), sulphate (5.72±3.57 mg/L) and biological oxygen demand (2.42±1.13 mg/L) were below set standard for natural freshwater bodies. Transparency (1.57±0.37 m) exceeded the acceptable limit of ≤ 0.4 m while phosphate (0.10±0.0 mg/L) was above the concentration of >0.02 mg/L for eutrophic aquatic environments. The higher values of transparency and phosphate above the permissible limits signify eutrophication of the Upper Reaches of Orashi River.

5.1.5 Studies on sediment parameters

Sediment has been described as the ultimate sink of contaminants in the aquatic systems (Davies and Abowei, 2009). Sediment is the loose sand, clay, silt and other soil particles that settle at the bottom of a body of water (United State Environmental Protection, USEPA, 2000). It can come from soil erosion or from the decomposition of plants and animals.Wind, water and ice help carry these particles to rivers, lakes and streams. Sediment texture refers to the proportions of sand, silt and clay below 2000 micrometers (2mm) in diameter in a mass of sediment Sand is coarse and gritty, silt is smooth like flour and clay is sticky and plastic when wet. Sediment that exhibits a combination of the three properties is said to have a loam texture.

5.1.5.1 The study on sediment quality of lower reaches of Okpoka Creek, Niger Delta, Nigeria by Davies and Abowei (2009) showed that the sediment of this creek was sandy-loam (consisting of sand, silt and clay, typical of intertidal estuarine mangrove swamps) and acidic (low pH) with high level of total organic carbon indicating organic pollutants. The measured physical and chemical parameters of sediments varied significantly within the creek (P<0.05).

and may be caused by photosynthesis and respiration cycles of algae, periphyton and macrophytes in eutrophic waters.

4.4.2.2 Dissolved oxygen

Dissolved oxygen is probably the most universally applied water quality criterion. It is the dissolved gaseous form of oxygen. Oxygen enters water by diffusion from the atmosphere and as byproduct of photosynthesis from algae and other plants (**Davies**, 2014). It is essential for respiration of fish and other aquatic organisms (USEPA, 2002). It is required for bacterial decomposition of plant and animal matter. The properties of solubility and especially the dynamics of oxygen distribution in lakes, reservoirs and other aquatic environments are basic to the understanding of aquatic organisms. The minimum concentration of dissolved oxygen to support fish and other aquatic life is about 4 mg/L (USEPA, 2002). Typically, the concentration of dissolved oxygen in natural surface water is less than 10 mg/L. The solubility of atmospheric oxygen, that is, saturation in freshwater ranges from approximately 15 mg/L at 0˚C to 8 mg/L at 25˚C at sea level. Seawater saturation ranges from 11 mg/L at 0˚C to 7 mg/l at 25˚C (McNeely *et al.*, 1979).

Dissolved oxygen depends on temperature, salinity, turbulence, atmospheric pressure, microbial and biotic respiration, and the photosynthetic activity of algae and macrophytes (**Davies**, 2014). The amount of dissolved oxygen in most aquatic ecosystems decreases at higher temperatures, and inversely proportional to altitudes and salinities (Boyd, 1981). It varies greatly from organism to organism, thus a single arbitrary oxygen concentration for all organisms in all types of waters is not practicable. Water saturated with dissolved oxygen is acceptable for all uses except for industrial application, since the presence of dissolved oxygen increases the corrosiveness of water (McNeely *et al.,* 1979). Dissolved oxygen of above 5.0 mg/L is recommended as the desirable range for fish production. Fish can survive in dissolved oxygen range of 1.0-5.0 mg/L but growth will be slow for prolonged exposure (Boyd, 1981). Death of fish will occur below 1 mg/L.

Dissolved oxygen levels are strongly influenced by point source discharges thus it is used in preliminary evaluation of in-stream water quality. It may provide reliable evaluations of the potency of management efforts to control non-point source discharges and improve habitat conditions because of its sensitivity as an indicator of inland water quality. Pollutants from storm water runoff and point-source wastewater discharges contain organic materials and nutrients that contribute to consumption of dissolved oxygen.

4.4.2.3 Biological oxygen demand (BOD)/biochemical oxygen demand (BOD)

Biological oxygen demand (BOD) is of vital importance in pollution monitoring (**Davies**, 2014). It is an index of aquatic pollution or key indicator of the oxygenation status of aquatic environment. Biochemical oxygen demand is an approximate measure of the amount of biochemically degradable organic matter within a sample. It is defined as the amount of oxygen microorganisms require to oxidize organic material to an inorganic form. A high BOD load can pose a threat to the aquatic environment by depressing the dissolved oxygen

oxygen demand were significantly higher than wet season values. Total organic carbon (TOC), phosphate and ammonia values at both seasons were above FEPA and USEPA permissible levels for natural aquatic environment. Nitrate, phosphate and sulphate had significant seasonal variations. The presence of high levels of TOC and phosphate especially at wet season indicates organic pollution and stress in this creek.

5.1.4.3 The tidal (low and high) influence on the physico-chemistry quality of Okpoka Creek, Nigeria was studied by Davies (2014). Tide demonstrated significant influence on the measured physico-chemical variables: temperature, turbidity, electrical conductivity, pH, dissolved oxygen, biological oxygen demand, total dissolved solids, calcium and hardness ($P<0.05$). The values of the measured physico-chemical parameters and nutrients were higher or lower at low tide for some parameters and vice versa. The recorded range of TOC concentrations at both tides was above the 1 to 30 mg/L for natural aquatic bodies. Phosphate and ammonia exceeded FEPA and USEPA acceptable levels of 0.01 mg/L for natural water bodies. Nitrate and phosphate had significant tidal variations ($P<0.05$). Increasing anthropogenic wastes especially dredged materials, slaughter effluents and raw human faeces lead to high organic loads.

5.1.4.4 Nevertheless, Davies *et al*. (2018c) studied the physico-chemical variables of the Upper Reaches of Orashi River, Niger Delta, Nigeria. The study showed that pH (6.07 ± 0.54), dissolved oxygen (5.63 ± 1.20 mg/L), total dissolved solid (53.18 ± 4.48 mg/L), conductivity (59.16 ± 3.89 µs/cm), total alkalinity (6.49 ± 1.06 mg/L), salinity (0.02 ± 0.01 ‰), nitrate

Rotifera and Protozoa) and 26 species dominated Copepoda. There was significant spatial variation between Copepoda and the other three families of zooplankton ($p<0.05$). The spatial (station) and temporal (month) species composition, diversity and abundance of these zooplankton taxa were different.

5.1.4 Studies on water physico-chemical parameters

My studies on water physico-chemical parameter unveiled their dynamic nature as well as bioindicators of health, stress, perturbation, pollution and nutrient status of inland waters.

5.1.4.1 Kwen *et al*. (2012) analyzed the **temperature, dissolved oxygen, hydrogen ion concentration (pH) and transparency conditions from three stations in the Upper Nun River, Niger Delta, Nigeria. That study revealed that t**here was no significant difference in transparency and pH between stations, but dissolved oxygen and temperature showed significant difference between stations ($P<0.05$). The results from the correlation matrix analysis showed significant correlation between the variables at different stations. Positive association was noticed indicating functional similarity. The varying magnitude of the relationship between the water variables in Upper Nun River of the Niger Delta area was attributed to micro habit difference.

5.1.4.2 Davies (2013) studied the **seasonal (wet and dry) variation of the physico-chemistry quality of a tributary of the Bonny Estuary, Rivers State, Nigeria.** Season (wet and dry) has varied effects on the physico-chemical characteristics of Okpoka Creek. Turbidity and temperature showed significant seasonal variations while transparency demonstrated insignificant seasonal differences. Dry season dissolved oxygen and biological

concentrations to levels that affect aquatic organisms. Waters with BOD levels less than 4 mg/L are considered clean but those with levels greater than 10 mg/L are regarded as polluted as they contain large amounts of degradable organic material (McNeely *et al.,* 1979).

4.4.2.4 Chemical oxygen demand (COD)

Chemical oxygen demand (COD) is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant. COD is greater than BOD for any given sample and is typically less than 20 mg/L in unpolluted waters.

4.4.2.5 Salinity

Salinity is the total salt content of the aquatic environment. It is the total amount of dissolved inorganic salts in the inland waters. Salinity is measured, in most cases, in parts per thousand (ppt or ‰). It is one of the major factors influencing algal zonation and distribution within the estuaries, both in terms of range of values and rate of change. Salinity affects the distribution patterns and relative abundance of organisms (Chindah, 2004). It naturally increases towards the sea. Factors influencing salinity are sunlight, frequent precipitation, rates of evaporation, amount of dissolved inorganic salts. **Salinity is a useful indicator of estuarine hydrography and habitat potential. It provides a direct measure of the relative influence of the sea and freshwater sources on an estuary.**

4.4.2.6 Electrical Conductivity (EC)

Electrical conductivity is the ions capacity of the water and how these ions are being conducted or distributed. It is measured in microsiemens per centimeter (μS/cm). This ability depends on the presence of ions and on their total concentration, mobility and valence (APHA, 1998).Carbonates and other charged particles increased the conductivity of a water body. It also, like salinity, naturally increases towards the sea. Conductivity is used to determine salinity and is actually a measure of the ability of water to conduct an electrical current. Conductivity is proportional to the concentrations of total dissolved solids (**Davies**, 2014) and major ions, and its measurement is influenced by the amount of electrical charge on each ion, ion mobility and temperature of the water (**Davies**, 2014). **Conductivity has proven to be useful in determining the extent of influence of run-off and effluent discharges in aquatic systems.** EC is important for the growth of plants and animals and found naturally in low concentrations in aquatic environments. It can pose problems to life in freshwater environment and affect its utilizations by man when salts concentrations is too high.

4.4.2.7 Total dissolved solids (TDS)

The total dissolved solid is an index of the amount of dissolved substances (sodium, calcium, magnesium, phosphates nitrates, potassium, sulphates and chlorides) from anthropogenic sources in a water body. TDS are regarded as solids that can pass through 2 μm sieve. It is referred to as a watch dog for environmental test. It is also the measurement of the combined content of all inorganic and organic substances contained in a liquid in

environment under stress. Zooplankton demonstrated significant temporal variation ($P<0.05$). Water temperature 28.6±0.06°C, turbidity 3.6±0.32 NTU and transparency 0.7±0.01m showed significant temporal variations ($P<0.05$). Phosphate demonstrated significant spatial variation ($P<0.05$).

5.1.3.5 The paper, Ikenweiwe *et al*. (2011) on the **abundance of planktonic organisms in Lekan-Are Lake, Ogun State, Nigeria identified** three major groups of zooplankton (Cladocera, Copepoda and Rotifera) dominated by the Copepoda in the three habitats 83.37% (shore), 82.73% (surface) and 80.26% (bottom). The presence of dominant Copepoda shows the lake is perturbed and under stress.

5.1.3.6 The effects of tide (low and high) on zooplankton community of a tributary of Upper Bonny Estuary, Niger Delta, Nigeria, were studied by Davies and Ugwumba (2013c). Phosphate had significant tidal variations ($P<0.05$). A total of 85 species of zooplankton were identified with most of the species more abundant at low tide than high tide, suggesting retention and settlement in the Okpoka Creek at low tide. The zooplankton were sensitive to both low and high tides. The study recorded dominant copepods and Euphasiacea being the second dominant and high levels of nutrients (ammonia and phosphate) indicating organic pollution and stress due to. increasing dredged materials, slaughter effluents and raw human faeces.

5.1.1.7 The article, Davies and Nwose (2018b) on zooplankton community of the Upper Reaches of Orashi River documented a total of 357 cell counts/ml of zooplankton from 4 families (Copepoda, Cladocera,

-chemical parameters. The results indicated characteristic species and distribution of zooplankton in Elechi Creek during the dry months. Also, it provided information on the influence of some physic-chemical parameters on the zooplankton abundance.

5.1.3.2 The research work of **Davies** and Otene (2009) on **zooplankton community of Minichinda Stream, Port Harcourt, Rivers State, Nigeria** identified dominant class Protozoa (68.15%) and species, *Askenasia faurie kahl* as well as phosphate level (above 0.10 mg/L allowable limit) indicating organic pollution from anthropogenic sources. Protozoa and Rotifera abundances showed significant spatial variations ($P<0.05$). Temperature (30.02±0.01ºC), pH (6.13±0.07), dissolved oxygen (DO) (7.13±0.15mg/l) and phosphate ($P0_4$) (0.10±0.02mg/l) were similar in all the study stations ($P>0.05$). Other measured physico-chemical parameters showed significant spatial differences ($P<0.05$).

5.1.3.3 In the article, **Davies *et al*. (2009b)** on s**easonal abundance and distribution of plankton of Minichinda Stream, Niger Delta, Nigeria, t**he wet season zooplankton (1924 counts/ml) were higher than the dry season zooplankton (1426 counts/ml); Protozoans dominating at both seasons. The presence of dominant Protozoans and high level of phosphate indicate organic pollution in this stream.

5.1.3.4 The study of *Davies (2009c) on the* spatio-temporal distribution, abundance and species composition of zooplankton of Woji-Okpoka Creek, Port Harcourt, Nigeria *recorded* a total of 85 species dominated by Copepods (43.4%) signifying an

molecular, ionized or micro-granular (colloidal sol) suspended form. It is used as an indicator of the aesthetic characteristics of drinking water and aggregate indicator of the presence of various chemical contaminants. It is not a primary pollutant, as it is does not compromisingly impact the health of aquatic lifes and human (Atekwana *et al*., 2004). The presence of such solutes alters the physical and chemical properties of water. Sources are residential runoff, hard water ions, fertilizer in agricultural runoff, salinity from minerals or returned water from migration and acidic rainfall, leached contaminants in soil runoff, clay rich mountain waters, point source water pollution discharge from industrial or sewage treatment plants. TDS due to dissolved salts affect many aquatic organisms (**Davies**, 2014). The salt dehydrates the skin of animals and high TDS give unpleasant mineral taste and/or cause laxation effect of water. More exotic and harmful elements of TDS are pesticides from surface runoffs.

4.4.2.8 Total suspended solids (TSS)

Total suspended solids are the dry weight of particles trapped by a filter of 2 µm sieve and formerly known as non-filterable residue (NFR). Sources of TSS are suspended rubber and plastic materials. It is used to evaluate the quality of wastewater after treatment in a wastewater treatment plant. It is known as a conventional pollutant in the US Clean Water Act.

4.4.2.9 Total organic carbon

The total organic carbon contains the dissolved and particulate organic carbon. Higher levels in water indicate organic pollution and stress from anthropogenic inputs (**Davies**, 2014). Water with less than 3.0 mg/L total organic carbon is said to be relatively clean (McNeely *et al*., 1979). Sources are natural carbonates, bicarbonates, hydroxide, borates, silicates, phosphates and organic substance concentrations, sodium salts compounds and bicarbonates of alkaline earths

4.4.2.10 Alkalinity

Alkalinity is the buffering (alkaline) capacity of the water or the capacity of bases to neutralize acid (**Davies**, 2014). It is caused by the presence of bicarbonate, carbonate and hydroxyl ions in water. Bicarbonate is the major source of alkalinity and comes from the action of carbon dioxide in percolating water on basic minerals in soils and rocks. Alkalinity provides buffering effect to resist alterations in pH and also increases with increase in pH (**Davies**, 2014). For the aquatic environment to be protected, guidelines stipulate that alkalinity must be maintained at natural background levels with no sudden variation (Environmental Studies Board, 1973). Sources are bases such as carbonate, bicarbonate hydroxides and phosphates berates. Brackish water alkalinity is greater than freshwater alkalinity.

4.4.2.11 Chloride

Chloride indicates the dissolution of salt deposits in form of ions (chloride ions, Cl^-) in natural water. High concentrations of chloride signify pollution by sewage, industrial wastes, intrusion of sea water or other saline water. It is not harmful to human health but high chloride level has deleterious effect on metallic pipes and structures as well as on agricultural plants. Too high chloride levels increase rates of corrosion of metals in distribution system, depending on the alkalinity of water. This can lead to increased concentrations of metals in

quality of aquatic environments (Davies *et al*. (2008b).They are useful indicators of future fisheries health because they are a food source for organisms at higher trophic levels. Zooplankton biomass, abundance and species diversity are used to determine the conditions of the aquatic environment (Davies *et al*. (2008b). Generally, copepods dominate the zooplankton community in most aquatic ecosystems (Ikenweiwe *et al*., 2011).

The season of maximum abundance of planktonic organisms differ in water bodies. Also, their composition and distribution vary from place to place and year to year due to the dynamic nature of the aquatic systems (Davies *et al*. (2008b).These characteristics of different species of zooplankton can sometimes help scientists distinguish one water mass from another.The productivity of aquatic systems including the production of fish which depends on the quality and quantity of planktonic organisms present may be influenced. Many factors such as dissolved oxygen, transparency, salinity, pH and temperature influence the occurrence, abundance and distribution of planktonic organisms.

My research works on zooplankton also documented them as secondary producers, bioindicators of productivity of the aquatic bodies, fisheries production, health, stress, perturbation, pollution and nutrient status of inland waters.

5.1.3.1 The study of Davies *et al*. (2008b) on zooplankton of Elechi Creek, Niger Delta, Nigeria revealed the presence of dominant copepods and high level of phosphate indicating an environment under stress and organic pollution. The abundance of zooplankton did not vary significantly in the stations (2>1>3>4>5) and there were slight fluctuations in the measured physico (diatoms), *Cladophora glomerata*, *Scenedesmus sp* (green-algae), *Euglena acus* (euglenoid), *Anabeana spiroides* (blue-green algae) and *Ceratium furca* (dinoflagellate) are present at either or both tides.

5.1.2.3 The article of Otene and Davies (2013) on **the epipelic algal distribution of upper Bonny Estuary, Amadi-Ama creek, Niger Delta in relation to sediment quality indices** indicated organic pollution. The most dominant taxon, Bacillariophyceae and species, *Cyclotella operculata as well as* high phosphate levels above the USEPA permissible limit of 0.10 mg/L in natural aquatic bodies were observed. Sediment parameters such as pH, conductivity, nitrate, sulphate, phosphate and chlorophyll'a' except temperature exhibited significant spatial difference ($p<0.05$). The observed chlorophyll'a' level in this study, classified Amadi-Ama Creek between mesotrophic and euthrophic level of productivity.

5.1.3 Studies on zooplankton

Zooplankton are planktonic animals that range in size from microscopic to macroscopic. They are classified unto three groups (namely microszooplankton, mesozooplanton and macrozooplankton) based on size. They are microszooplankton (less than 200 microns in size; examples are protozoa and rotifers); mesozooplanton (between 200 microns and 2 millimeters in size); macrozooplankton (greater than 2 millimeters in size, examples are amphipods, shrimps, fish larvae and gelatinous zooplankton or jelly fish). The zooplankton are so closely linked to the environment and they tend to respond to changes more rapidly than do larger aquatic animals such as fish, thus these organisms have proved valuable indicators of apparent and subtle alterations in the

supply (WHO, 2011). **Salinity and conductivity** as well as municipal runoff and high evaporation rate of water **affect chloride.**

4.4.2.12 Calcium

Calcium contributes to the total hardness of water. It is an important element of the body. High concentrations of calcium in water are relatively harmless to all organisms and may reduce toxicity of certain chemical compounds to fish. Calcium concentrations vary with different degrees of leaching from the surrounding soils, high amounts of human faeces and animal wastes as well as the industrial wastes, salinity and conductivity. Sources in water supplies are due to water movement over deposits of limestone, dolomite, gypsum and gypsei-ferous shale.

4.4.2.13 Magnesium

Magnesium is a common content of natural waters. Natural sources are alkaline earth and salinity. It is an important element of the body like calcium.

4.4.2.14 Hardness

Calcium and magnesium (polyvalent cations) concentrations are used to measure the hardness concentrations in aquatic environments, that is, it is the sum of calcium and magnesium concentrations, expressed as calcium carbonate ($CaCo_3$) in mg/L. It is an important parameter to detect water pollution. Hardness exists mainly as bicarbonates of calcium and magnesium and a lesser degree in form of sulphates and chlorides. It is the property of water that prevents lather formation with soap and produces scale in hot water systems. Sources are metallic ions, soil leaching. The permissible limits of hardness for water are based on palatability, corrosion and incrustation (WHO, 2011). High concentration of hardness may cause health diseases and kidney stones.

4.4.3 Nutrients of inland waters

Nutrients (ammonia, nitrate, phosphate, sulphate) are used as index of organic pollution and their main sources in the aquatic environments are organic matter (plants, animals, domestic wastes containing human faeces, residual fertilizers, wet and dry precipitation from burning of fossil fuels, oxidation of organic materials and burning of fossil fuel, etc). Other source is industrial effluents. Nutrients availability especially phosphorus, structure the algae assemblage (Roelke *et al.,* 2007).

4.4.3.1 Ammonia

Ammonia contributes to the fertility of water since nitrogen is an essential plant nutrient. It is also one of the most important pollutants in aquatic environment because of its relative high toxic nature and its ubiquity in surface water systems. Ammonia enters natural water systems from several sources including industrial wastes, sewage effluents, coal gasification and liquefaction conversion process plants and agricultural discharge including feedlot runoff.

4.4.3.2 Nitrate

Nitrate is an important nitrogen source for phytoplankton in aquatic ecosystem. It is present in much larger quantities in natural water bodies with available oxygen (USEPA, 2002). Sources of nitrogen include fertilizers, human and animal wastes, atmospheric deposition in rainwater and yard waste or other plant material that reaches the streams. Nitrogen can also diffuse from the

❖ **Factors affecting periphyton growth**

The factors are the same as that of phytoplankton.

My research works on periphyton unveiled them as primary producers of food for zooplankton and other fishes, bio-indicators of productivity of the aquatic environments, fisheries production, health, stress, perturbation, pollution and nutrient status of inland waters.

5.1.2.1 In Davies (2009a) on epiphytic diatoms growing on *Nypa fructican* of Okpoka Creek, Niger Delta, Nigeria and their relationship to water quality, the documented pollution indicator genera were *Navicula*, *Nitzschia* and *Synedra* and they recorded different percentages of distribution within the creek. Phosphate and ammonia exceeded the FEPA and USEPA of acceptable levels for natural water bodies and varied significantly within the stations, months, year and tides. The high nutrient status favours the high abundance and distribution of epiphytic diatoms. The recorded implicative genera and high phosphate as well as ammonia indicate organic pollution from anthropogenic sources.

5.1.2.2 The paper, Davies and Ugwumba (2013b) on **tidal Influence on epiphyton population of Okpoka Creek, Upper Bonny Estuary, Nigeria revealed that l**ow and high tides affected the species composition, diversity, abundance and distribution of epiphyton assemblage of Okpoka Creek. Diatoms were the dominant taxa and red algae, the least. They were sensitive to both low and high tides. Organic pollution-indicator species (*Navicula placentula*, *N. recognita*, *N. pusilla*, *N. similis*, *N. gastrum*, *Nitzschia bilobata, N. apiculata*, *N. lanceolata*, *N. acuta*, *N. sigma*, *N. linearis*, *Synedra ulna, C. menephiniana*, *Cocconeis placentula*

❖ **Utilizations of periphyton**

Periphyton are used as follows as:

- Important food source for invertebrates, tadpoles, snails and some fish.
- Important indicator of water quality
- Important natural and historical indicator of ecosystem health
- As a primary producer, stablilisers the water column and produces important energy input to both detritus and the grazing communities.
- A cheap source of supplementary energy input that can be supplied by all fish in the open waters.
- Fish production through aquaculture; perphyton is produced on different substrate types (bamboo, jute sticks, etc).
- Improved water quality by trapping suspended solids in the periphyton mat, which also takes up ammonia and nitrate, produces oxygen, breaks down organic matter and increases nitrification.
- Synergistic effects from two interrelated processes; increase in available food resources and improvements in environmental conditions.
- Regulation of submerged vegetation. Increased epiphyton loads is detrimental to the success of the host plant.
- Indirectly and directly serve as a major regulator of nutrient dynamics in lakes.
- Energy input to food webs

air into aquatic bodies. Nitrogen in solutions may be used by those blue-green algae capable of nitrogen fixation. Most surface waters contain nitrate (<5 mg/L) but when the concentration is up to 5 mg/L is a reflection of organic pollution as one major source of nitrate is human and animal wastes. Although surface waters may contain <1 mg/L or >100 mg/L nitrate. Nitrate concentrations in surface waters may fluctuate with season; higher in cold months and rainy season.

4.4.3.4 Phosphate

Phosphates are found in the natural aquatic environments as orthophosphates, condensed phosphates and phosphates. Sources of phosphate are natural inputs from decomposition of organic matter, geological formation and anthropogenic input of domestic and industrial wastes containing human faeces, sewage, inorganic fertilizers and detergents, containing phosphates. It is required for plant growth and metabolic reactions in living organisms. It has effects on aquatic bodies; phosphate-induced algal blooms may increase dissolved oxygen through photosynthesis but after leads to oxygen depletion due to oxygen-consuming decomposition activity by bacteria. Phosphate impacts on the health of the aquatic ecosystem when present in high concentration; exceeded the allowable levels of 0.10 mg/L.

4.4.3.5 Sulphate

Sulphate (SO_4^{2-}) is the stable, highly oxidized form of sulphur; soluble in water. Sources are both natural and anthropogenic namely oxidized organic materials, wet and dry precipitation from burning of fossil fuels, industrial effluents from tanneries, sulphite-pulp mills, textile plants, sulphuric acid and metal working industries, bacterial oxidation of reduced sulphur compounds (metallic sulphides and organo-sulphur compounds), leaching from sedimentary rocks.

4.4.4 Heavy metals

Heavy metals are metalloids with relative high atomic weight and specific gravity of ⩾ 5 cm (WHO, 2011). Heavy metals can be described as elements that are commonly associated with pollution and toxicity problems. They are classified into two groups: essential and non-essential heavy metals. Essential ones have biological functions (play important role in biodiversity) and examples are chromium, nickel, iron, zinc, copper and manganese. They become toxic when their concentrations exceed tolerable limits (**Davies** *et al*., 2007). The non-essential metals have no biological functions and are highly toxic even at low concentrations (**Davies** *et al*., 2006c). Examples are mercury, lead and arsenic. Sources of heavy metals are natural (volcanic activity, rock weathering, volcanic eruptions, crude oil, geology of the area, soil erosion, dissolution of water soluble salts) and anthropogenic (municipal wastewater, agricultural wastes, industrial effluents, petroleum, pesticides, herbicides, fungicides, dredging, oil exploration in off shores, mining, lead smelting, storage batteries, emissions from electroplating, metal finishing, textile, plating, ceramic and glass industries and runoff resulting from rainfall) (Roy, 2010). Inputs of heavy metals from anthropogenic sources exceed those from natural sources (**Davies** *et al*., 2007) and have contributed to the steadily increasing metallic contaminants in aquatic and terrestrial environments in most parts of the world". Metals generally exist in low levels in water and reach considerable concentration in sediments and biota. Aquatic pollution with heavy metals has become a global problem in recent years

functional components of the lake communities. They may contribute substantially to whole lake primary productivity in shallow lakes and thus provide an important energy input to both detritus and grazing food chains. A wide range of fish and benthic invertebrates including snails, chironomids, mayflies, oligochaetes and several groups of crustaceans include periphyton in their diet while some species feed on them as an alternative. Several studies have shown that increased epiphyton loads are detrimental to the success of the host plant (Davies, 2009a). It has therefore been suggested that epiphyton is one of the most important regulators of abundance and depth distribution of submerged vegetation in lakes. Periphyton abundance can be used as a measure of river health (John and Mark, 2004). Healthy streams typically have little obvious periphyton because algae are eaten by invertebrates. Nuisance blooms are usually a symptom of a system stressed by factors like over-supply of nutrients and high temperatures (that increase algal growth rates but stress some invertebrate grazers). It makes a stream unattractive for swimming, useless for angling, clogs up water intakes and reduces biodiversity by making the streambed habitat unsuitable for many sensitive invertebrate. Periphyton are also used for water quality evaluation (Davies, 2009a).

❖ Types of periphyton

There are basically five types of periphyton

- Epilithon/epilithic (on rock within the shoreline splash zone (eulittoral zone)
- Epiphyton/epiphytes (on macrophytes)
- Epixylon (wood)
- Episammon (sediments)
- Epipelon (muddy sediments)

S/No.	Water body	Observed CyanoHAB genera	Observed Bacillario HAB genera	Observed DinoHAB genera	Observed ChrysoHAB genera	Reference
1	Lower reaches of Okpoka Creek, Rivers State	*Microcystis*, *Anabeana*, *Lyngbya*, *Oscillatoria*	*Melosira*, *Nitzschia, Navicula, Melosira, Cyclotella, Synedra, Coscinodiscus, Cymbella, Biddulphia*	*Ceratium*	*Dinobryon*	Davies *et al*. (2008)
2	Elechi Creek, Rivers State	*Microcystis*, *Anabeana, Lyngbya, Oscillatoria*	*Melosira, Navicula, Nitzschia, Cymbella, Cyclotella, Coscinodiscus, Synedra, Biddulphia*	*Ceratium*		Davies *et al*. (2009a)
3	Minichinda Stream, Rivers State	*Anabaena, Oscillatoria, Lyngbya*,	*Melosira, Cyclotella, Nitzschia, Navicula, Synedra*		*Dinobryon*	Davies *et al*. (2009b)
4	Upper reaches Okpoka Creek, Rivers State	*Microcystis*, *Anabeana*, *Lyngbya*, *Oscillatoria*	*Melosira*, *Nitzschia, Navicula, Melosira, Cyclotella, Synedra, Coscinodiscus, Cymbella, Biddulphia*	*Ceratium*	*Dinobryon, Phyllosiphon*	Davies and Ugwumba (2013)
5	Oya Lake, Bayelsa State	-	*Melosira*	-	-	Davies *et al*. (2015)
6	Amadi-Ama Creek, Rivers State	*Microcystis*, *Anabeana*, *Oscillatoria*	*Cyclotella, Melosira, Navicula, Nitzschia, Synedra,*	-	-	Otene and Davies (2013)
7	Upper Reaches of Orashi River, Rivers State	*Microcystis*, *Oscillatoria*	*Cyclotella, Melosira, Coscinodiscus, Cymbella, Synedra*	-	-	Davies *et al*. (2018)

5.1.2 Studies on periphyton

❖ **What is periphyton?**

Periphyton is defined as a complex mixture of algae, heterotrophic microbes or micro invertebrates and detritus that is attached to submerged surfaces in most aquatic ecosystems. There five types of periphyton based on the hard surfaces they are attached to. Periphyton acts as both structural and

because they are indestructible and most of them have toxic effect on organisms (**Davies** *et al*., 2007). These metals cannot disappear from the environment because they are elements; they can only be transferred from one place to another.

4.4.5 Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are a group of chemicals that are formed during the incomplete refining of crude oil (such as the illegal refinery, KPO FIRE), burning of coal, oil, gas, wood, garbage, or other organic substances, such as tobacco and charbroiled meat (**Davies** and Abolude, 2016). There are more than 100 different PAHs. They generally occur as complex mixtures (for example, as part of combustion products such as soot), not as single compounds (**Agency for Toxic Substances and Disease Registry** (ATSDR**, 1995)**.

4.4.6 Acceptable Ranges of Physical and Chemical Properties of Inland Waters

Tables 11- 15 show the acceptable ranges of some physical and chemical parameters by some regulatory bodies or authorities. Nutrients, heavy metals and polycyclic aromatic hydrocarbons are also chemical parameters of the aquatic bodies.

Table 11: Acceptable ranges of some physical parameters

Parameter	Standard
Temperature (°C)	0 ºC (under ice cover) - 40 ºC (in hot springs) (McNeely *et al*., 1979)
Depth (m)	5-20 (UNESCO/WHO/UNEP, 1996)
Transparency (m)	0.4 or less (UNESCO/WHO/UNEP, 1996)

Table 12: Acceptable ranges of some chemical parameters

Parameter	Standard
Elec. Cond. (µS/cm)	340-700 (µS/cm) (WHO, 2011)
pH	6.0-9.0 (UNESCO/WHO/UNEP, 1996)
Alkalinity (mg/L)	30-500 (UNESCO/WHO/UNEP, 1996)
Dissolved oxygen (mg/L)	5.0-9.0 (UNESCO/WHO/UNEP, 1996)
BOD (mg/L)	3.0-6.0 (UNESCO/WHO/UNEP, 1996)
Chemical oxygen demand (mg/L)	15 (UNESCO/WHO/UNEP, 1996)
TDS (mg/L)	≤500 (WHO, 2011)
TSS (mg/L)	25 (UNESCO/WHO/UNEP, 1996)
Chloride (mg/L)	300 (UNESCO/WHO/UNEP, 1996)
Mineral oil (mg/L)	0.05 (UNESCO/WHO/UNEP, 1996)

Elec. Cond. –Electrical conductivity; TDS- Total dissolved solids; TSS-Total suspended solids; BOD- Biological oxygen demand

Parameter	Standard
Sulphate (mg/L)	100 (UNESCO/WHO/UNEP, 1996)
Phosphate (Ortho) (mg/L)	0.1 (USEPA, 1996)
Nitrate (mg/L)	⩽ 5 mg/L (McNeely *et al*., 1979

Table 14: Acceptable ranges of some heavy metals of surface water

Parameter	Standard
Iron, Ferric (mg/L)	0.3 (FEPA, 1991)
Iron, Ferrous (mg/L)	0.3 (FEPA, 1991)
Arsenic (µg/l)	10 (WHO, 2011)
Barium (µg/l)	700 (WHO, 2011)
Cadmium (µg/l)	3 (WHO, 2011)
Chromium (µg/l)	50 (WHO, 2011)
Cobalt (µg/l)	≤1.0 (WHO, 2011)
Copper (µg/l)	2000 (WHO, 2011)
Lead (µg/l)	10 (WHO, 2011)
Nickel (µg/l)	70 (WHO, 2011)
Zinc (µg/l)	⩽ 5 mg/L (McNeely *et al*., 1979
Iron (mg/L)	0.3 (WHO, 2011)
Mercury (µg/l)	6 (WHO, 2011)

5.1.1.8 The article, Davies and Nwose (2018a) on phytoplankton assemblage of the Upper Reaches of Orashi River revealed a total of 798 cell counts/ml of phytoplankton from 3 families (Bacillariophyceae, Chlorophyceae and Cyanophyceae) and 24 species dominated by diatoms (Bacillariophyta). There were no significant spatial variation between Bacilliariophyta, Chlorophyta and Cyanophyta ($p<0.05$). The species composition, diversity and abundance of these families varied within the stations (spatial) and months (temporal). The recorded *Melosira varians* (Bacillariophyceae), *Oscillatoria limosa* and *O. lacustris* (Cyanophyceae) denotes nutrient enrichment of this River.

5.1.1.9 Observation of harmful algal blooming genera in some water bodies in Rivers and Bayelsa States are shown in Table 24. From my studies so far in the Niger Delta, some major harmful algal bloom-forming genera in some aquatic environments in Rivers and Bayelsa States were recorded. These findings indicate that these water bodies are under stress from causative agents discussed above.

Table 16: Major harmful algal bloom-forming genera in some aquatic environments in Rivers and Bayelsa States

nutrients status favoured the growth of phytoplankton and epiphyton and in return the abundance of the zooplankton. The presence of these genera for phytoplankton and epiphyton; *Navicula, Nitzschia* and *Synedra* (diatoms), *Cladophora*, *Scenedesmus* (green algae), *Euglena* (euglenoid), *Anabeana*, *Microcystis* (blue-green algae) and *Ceratium* (dinoflagellate) as well as dominant copepods indicates an environment (Okpoka Creek) that is perturbed and organically polluted. The study thus recommends the discharge of treated and recycling of anthropogenic wastes to control eutrophication and pollution in this creek.

5.1.1.7 A p**reliminary study on phytoplankton and nutrients status of Oya Lake, Bayelsa State, Nigeria was investigated by Davies *et al*. (2015). The study revealed** a total of 420 counts/mL phytoplankton from 3 families (Bacillariophyceae, 13.1%; Euglenophyceae, 13.1% and Chlorophyceae, 73.8%), 8 genera and 11 species dominated by Chlorophyceae in terms of species composition and abundance indicating low productivity. The mean value of phosphate (0.21±0.07 mg/L) was above the USEPA permissible limit of 0.10 mg/L. The phytoplankton and measured nutrients varied with stations and months. The presence of dominant Chlorophyceae, low species composition, diversity, abundance and distribution of phytoplankton as well as high value of phosphate denotes that Oya Lake is perturbed and organically polluted. Also, the recorded *Melosira distans* and *M. granulata* indicates nutrient (phosphate) enrichment of Oya Lake.

Table 15: Acceptable ranges of some polycyclic aromatic hydrocarbons (PAHs)

Parameter (µg/l)	Standard
Naphthalene LM, NC	30 (WHO, 2011)
Acenaphthene LM, NC	60 (USEPA, 2007)
Acenaphthylene LM, NC	60 (USEPA, 2007)
Fluoranthene LM, NC	300 (WHO, 2011)
Anthracene LM, NC	2000 (WHO, 2011)
Phenanthrene LM, NC	60 (USEPA, 2007)
Fluorene LM, NC	300 (WHO, 2011)
Chrysene HM, WC	0.2 (USEPA, 1996)
Pyrene HM, NC	200 (WHO, 2011)
Benzo(a)anthracene HM, C	0.1 (USEPA, 1996)
Benzo(b)fluoranthene HM, C	0.2 (USEPA, 1996)
Benzo(k)fluoranthene HM,	0.2 (USEPA, 1996)
Benzo(a)pyrene HM, SC	0.2 (USEPA, 1996)
Dibenzo(a,h)anthracene HM, C	0.3 (USEPA, 1996)
Benzo(g,h,i)perylene HM, NC	200 (WHO, 2011)
Indeno(1,2,3-c,d)pyrene HM, C	0.4 (USEPA, 1996)
PAH, Total Detected	0.03 (total carcinogenic); 0.3 (total non-carcinogenic) (WHO, 2011)
Benzene LM, NC	300 (UNESCO/WHO/UNEP, 1996)
Toluene LM,NC	1000 (USEPA, 2007)
Ethylbenzene LM, NC	700 (USEPA, 2007)
m,p-Xylene LM, NC	10,000 (USEPA, 2007)
o-Xylene LM, NC	10,000 (USEPA, 2007)
Sum of detected Xylenes	500 (WHO, 2011)

LM-lower molecular; HM-higher molecular; NC-Non-carcinogenic; WC- weakly carcinogenic; C-carcinogenic; SC-strongly carcinogenic

4.5 Plankton and periphyton as biomonitors and bioindicators of pollution

The use of organisms for monitoring pollution is based on the belief that natural, unpolluted environments are characterised by balanced biological conditions and contains a great diversity of plants and animals with no one species dominating (Ruivo, 1972). A natural environment is composed of animal representations from all trophic levels. Pollutants kill the more sensitive organisms and may eliminate the enemies of the more tolerant species which in turn increase in numbers. **If the amount of waste discharge is increased, a further reduction of species occurs with the surviving species increasing further. If the discharge is great, the accumulation effect may kill the surviving species, leaving an area totally devoid of macroscopic life, therefore knowledge of what species are present is of paramount importance in evaluating the effect of waste discharge.** The food cycle is altered by adding waste discharges. Plants are killed and cannot repopulate because of direct or indirect toxic effect of the discharge, the elimination of suitable substrates through silting, the decreasing availability of sunlight from increase water turbidity or the combination of the factors with elimination of plants, herbivores can no longer exist. Carnivores may be eliminated directly and also by the absence of herbivores (**Davies *et al*., 2015)**. Further increases in the amounts of waste discharges eliminate the filter feeders leaving only the detritus feeders. Finally, if pollution is severe all detritus feeders are killed.

4.6 Some human activities affecting the Nigerian inland waters

Below are some human activities affecting the inland waters of Nigeria.

4.6.1 Oil and gas exploration and production

Nigeria is a major oil producing nation. The oil and gas are found in both onshore and offshore in the oil producing states (Niger Delta). There have been many cases of crude oil spills leading to aquatic pollution in these areas especially Rivers and Bayelsa States that have illegal artisan refineries (KPO FIRE) located close to the water bodies (**Davies**, 2008). These spills might have been caused by the followings: corrosion,

THE INDISPENSABLE CREATION IN OUR PLANET

Diatoms were the dominant phytoplankton while euglenoids were the passive (least) phytoplankters. They were sensitive and resilient to both low and high tides. Organic pollution indicator species: *Navicula gracilis, N. cuspidata, N. placentula, N. microcephala, N. bacillum, N. amphibola, Nitzschia sigma, N. bilobata, N. lanceolata, N. filiforms, N. longissima, Cymbella cuspidata, C. lata, Tabellaria fenestrata, Synedra ulna*, *Cyclotella meneghiniana*, *Cocconeis placentula*, *Pinnularia major* (diatoms), *Cladophora glomerata*, *Scenedesmus spp* (green algae), *Euglena acus* (euglenoid), *Anabaena spiroides*, *Microcystis pulverea* (blue-green algae), and *Ceratium furca* (dinoflagellate) were recorded at either only low, high or both tides. Phosphate and ammonia (organic pollutants) exceeded FEPA and USEPA acceptable levels of 0.10 mg/L and 0.10 mg/L, respectively, for natural water bodies indicating high nutrient status, organic matter, and potential pollutants in this creek. The flushing action of the tidal flows contributes to moving these pollutants down into this creek.

5.1.1.6 The article, c**omparative studies of the plankton, epiphyton and nutrients status of a perturbed creek, Niger Delta by** Davies and Jaja (2014a) documented a total of 158, 85 and 129 species of phytoplankton, zooplankton and epiphyton. Diatoms dominated the phytoplankton (62.9%) and epiphyton (35.4%) population. Copepods (43.4%) dominated the zooplankton community. Phosphate and ammonia exceeded international acceptable levels of 0.10 mg/L for natural water bodies indicating high nutrients status, organic matter and potential pollutants. The high index that was significant for Chrysophyceae and Xanthophyceae (P<0.05). For zooplankton, seasonal variations of species diversity indices were not significant (P>0.05). Conductivity, pH, nitrate, chloride and temperature showed significant seasonal variation (P<0.05). Also, the study **revealed** high level of phosphate (0.10 mg/L) and the presence of *Melosira varians, Anabaena flos-aquae and Oscillatoria lacustria signifying* nutrient enrichment of **Minichinda Stream**. However, *Spirulina substilissinna, a great important health food was observed. Wet season phytoplankton abundance (*6180 counts/ml, 57.97%*) was higher than dry season (*4480 counts/ml, 42.03%*)*.

5.1.1.4 The **abundance of planktonic organisms in Lekan-Are Lake, Ogun State, Nigeria published in** Ikenweiwe *et al*. (2011) observed marked seasonal variations in the phytoplankton of the lake (shore, surface and bottom). Four major groups of phyto-plankton were identified Baccilariophyceae (diatoms), Chlorophyceae (green algae) and Cyanophyceae (blue green) dominated by the green algae (63.3% in the surface and 54.8% in the bottom zone of the lake). The phytoplankton density was at its peak in sunny months of January to early June that coincided with the period of high temperature.

5.1.1.5 Tidal influence on nutrients status and phytoplankton population of Okpoka Creek, Upper Bonny Estuary, Nigeria was investigated by Davies and Ugwumba (2013a). The study revealed that tide has varied effects on the nutrients status and phyto-plankton community (in terms of species composition, diversity, abundance, and distribution) of Okpoka Creek.

poor maintenance of oil infrastructure, equipment failure, aged pipes, oil theft and sabotage. Crude oil (fossil fuel) contains polycyclic aromatic hydrocarbons (PAHs) (**Davies** and Abolude, 2016) which are classified as carcinogenic, mutagenic and teratogenic to many plants and animals, and regarded as pollutants of health concerns (Stogiannidis and Laane, 2015). Crude oil is also a source of heavy metals to surface waters.

4.6.2 Dredging

The goal of dredging operations around the Niger Delta has always been canalization for transportation purposes, reclamation of land for construction of harbours and for collection of sand for building and construction (Ekeke, Alfred-Ockiya and **Davies**, 2008). Dredging has pollution implication (**Davies** *et al*., 2008a). Dredged materials have high organic matter and clay (they are biological and chemical active) and tend to retain many contaminants of which they are subjected to mixing, re-suspension and transport. Dredging leads to sandy area; sandy sediment is low in organic matter and is much less effective in retaining metals and organic contaminant. It also releases toxic substances that have been deposited in the sediments due to mixing in the water column or leaching.

4.6.3 Poor wastes management

Wastes generated from various domestic and industrial sources are indiscriminately discharged into the aquatic environments and they are a major source of environmental pollution in Nigeria (**Davies** *et al*., 2008a; **Davies** *et al*., 2008b). These wastes change the physico-chemical and biological properties of the receiving aquatic bodies. For example, slaughter activities which include the slaughtering of pigs, cattle, goat, sheep and poultry produce approximately

84% of wastewater containing high organic loads including suspended matter and solid wastes which cause problem to dumping grounds.

Human activities alter the quality of virtually all aquatic habitats (except possibly polar seas) there degrading our indispensable resource.

5.0 MY CONTRIBUTIONS TO KNOWLEDGE

My contributions to knowledge reflect my life purpose to fight poverty, hunger and unemployment in Nigeria and Africa by boosting fish production through sustainable aquaculture and capture fisheries processes. In this inaugural lecture, I will be discussing my contributions to the dynamic freshwater and brackish water environments, looking at some of their dynamic physical, chemical and biological (phytoplankton, periphyton, zooplankton, macrophytes and finfish) features of the water and sediments.

5.1 Contributions to Hydrobiology and Limnology

5.1.1 Studies on phytoplankton

❖ **What is phytoplankton?**

The phytoplankton is the baseline of many food chains and webs in the aquatic bodies and is dependent on the activities of other microbial organisms majorly bacteria which change organic materials into the inorganic nutrients required by plants. The members of the phytoplankton are known as algae. The algae are special group of plants whose members range in size and organization from microscopic one-celled organisms (**microalgae**) of few micrometres diameter to highly organized multicellular macroscopic plants (**macroalgae/ seaweeds**, for example, Kelps). The plant body of an alga is

were *Melosira distans*, *M. granulata* , *M. japonica, M. listans* , *M. nummuloides, M. pusilla, M. undulata, M. varians, Navicula amphibola, N. bacillum, N. cuspidata, N. gracilis, N. microcephala, N. placentula, Nitzschia bilobata, N. filiforms, N. lanceolata, N. linearis, N. longissima, N. paradoxa, N. sigma (*diatoms), *Anabaena affinis, A. circirolis, A. spiroides, A. flos-aquae, Oscillatoria lacustris, O. limosa, O. princeps, O. rubescens O. tenuis* (blue-green algae), *Euglena acus*, *E. convoluta*, *E. gracilis*, *E. oxyuris*, *E. viridis*, *E. wangi* (Euglenoids), *Scenedesmus acuminatus* (green algae) and *Ceratium furcas (*Dinophyceae*)*. The high level of phosphate above the permissive limit (0.10 mg/L) showed that this creek is hypereutrophic and organic polluted. The high nutrients status favors the high abundance of phytoplankton. Health and medicinal *Spirulina* species recorded were *Spirulina laxissima, S. major, S. princeps and S. subtilissima.* The *Spirulina* is blue-green algae also known as oxygenic photoautotrophs

5.1.1.3 In Davies *et al*. (2009b) on seasonal abundance and distribution of **plankton of Minichinda Stream, Niger Delta, Nigeria,** some phytoplankton organic pollution indicator species documented were *Cyclotella operculata, Cyclotella comta, Cyclotella glomerata, Cyclotella kutzingiana, Cocconeis dimunuta, Nitzschia closterium, N. paradoxa, N. filiforms, Navicula rostellata, Synedra acus, S. ulna, S. cyclopum (Bacillariophyceae), Anabaenopsis finsbosgi, Anabaena flos-aquae (Cyanobacteria), Euglena tripteris, Euglena sangulena and Euglena vorax (Euglenoid)*. There were similar seasonal variations of species diversity indices for all phytoplankton taxa ($P>0.05$) except dominance

5.1.1.1 The article, Davies *et al*. (2008a) on phytoplankton of the lower reaches of Okpoka Creek, Niger Delta, Nigeria unveiled Baccilariophyceae as dominant taxon with 26 genera and 63 species with different species composition. *Melosira varians* (Baccilariophyceae, 351 cell counts) was the dominant diatom and *Anabeana spiroides* (blue-green) indicate a nutrient-enrich environment. The examined water physico-chemical parameters (temperature, pH, transparency, dissolved oxygen, salinity, total dissolved solids, chloride, alkalinity, phosphate and ammonia) favoured the high abundance and population of phytoplankton in this creek and varied within the stations. The presence of *Melosira varians*, *Anabeana spiroides*, *Euglena gracilis* (euglenoid) and *Ceratium hirudinea* (Dinophyceae) and high total dissolved solids (above 1,001-10,000 mg/L for brackish water) indicate organic pollution from anthropogenic sources.

5.1.1.2 The research work of Davies *et al*. (2009a) on the **phytoplankton community of Elechi Creek, Niger Delta, Nigeria-a nutrient-polluted Tropical Creek recorded** a total of 169 species of phytoplankton dominated by diatoms (33255 counts mL^{-}, 36%) and followed by blue-green algae (32909 counts/mL, 35.7%) were documented. The abundance of phytoplankton decreased downstream of this creek (1>2>3>4) except in station 5 with the highest phytoplankton abundance (23938 counts mL^{-1}). There was slight fluctuation in the measured physico-chemical parameters. Nutrient-enrichment and pollution-indicator species documented

called thallus (no differentiation into stem, roots and leaves). Phytoplankton is classified according to size as shown in Table 16 and Table 17. These tables show the different identification features used in plankton.

Table 16: Size grading of plankton organisms

Maximum size dimension	Plankton category
More than I mm	Macroplankton
Less than 1 mm, retained by nets of mesh size 0.06 mm	Microplankton
5-60 micrometres (μm)	Nanoplankton
Less than 5 μm	Ultraplankton

Table 17: Identification features of plankton organisms

S/No.	Feature	Remark
1	Cell shape	Constant or variable depending on the presence or absence of rigid cell wal
2	Cell dimensions	Measured in micrometres (μm = 0.001 mm). Eyepiece grid and stage micrometre are used.
3	Cell wall	Present (cellulose and pectin) or absent. Observable under high magnification. When the cell wall is absent, the cell is surrounded by its periplast/plasma membrane
4	Mucilage layer	Extension of the cell wall
5	Chloroplasts	The three major features to note are colour, number and shape.
6	Flagella	Number of flagella, their point of insertion in the cell, relative lengths when more than one is present, the presence or absence of bristle - like outgrowths or of a covering of fine hairs and presence of an additional flagellum - like structure (haptonema).
7	Reserve substances	Starch, oil, lipids, volutin globules, glycogen, cyanophycin (proteinaceous) and leucosin
8	Other cell features	Cell vacuoles, trichocysts (small thread-like bodies ejected by the cell, distinctive furrow or apical intucking

There are two types of phytoplankton; **photosynthetic** and **phagotrophic** phytoplankton. All its photosynthetic members contain chlorophyll a and it is borne in the chloroplasts except blue-green algae. Colour differences in chloroplasts are due to the nature and quantities of the auxiliary pigments present in addition to the green chlorophylls, for example, green algae chloroplasts have chlorophylls a and b, yellow-coloured carotene and xanthophylls pigments. Many members of the phytoplankton have chloroplasts which are brown, golden-brown or yellow, due to the green of the chlorophylls being masked by various xanthophylls pigments. All these pigments are lipid-soluble but water-soluble, proteinaceous pigments, the phycobilins are found in the blue-green algae and some flagellates, Class Cryptophyceae. The phycobilins are of two types; the phycocyanin (blue) and phycoerythrin (red). These pigments mask the chlorophylls and other pigments, giving the cell a blue-green or red colour depending on which predominates. Some unicellular planktonic algae are colourless thus they are phagotrophic; heterotrophic, that is, the cells engulf and digest solid organic particles. However, certain autotrophic pigmented algae exhibit phagotrophic characteristics. The colourless algae are heterotrophic. Many phytoplankton are heterotrophic and reproduce in the dark provided there is a carbon source while others are mixotrophic; they reproduce in light or dark conditions. Algae are grouped into twelve classes depending on the taxonomist. Table 18 shows the various classes and the habitats of the algae.

Table 23: Spatial distribution of the dinoflagellates in Nigerian coastal and inland waters and their potential harmful effects

Species (Distribution)	Harmful effects
Ceratium furca (BB, TB in LA)	Biota kills
C. fusus (BB in LA & Forc. In WA)	Biota kills
C. tripos (BB in LA)	Oxygen depletion
Dinophysis acuta (BB in LA)	Toxic
D. caudate (BB in LA & JT in CA)	Toxic
D. rotundata (BB in LA)	Toxic
D. tripos (BB in LA)	Toxic
Dinophysis sp. (BB in LA)	Potentially toxic
Gonyaulax diegenesis (Ijora in LA)	Oxygen depletion
G. scrippsae (BB in LA)	Oxygen depletion
G. spinfera (JT in CA)	Oxygen depletion
Gymnodinium sp (BB in LA)	Potentially toxic
Lingulodinium polyedrum (JT in CA)	Toxic
Prorocentrum lima (Ijora in LA)	Toxic
P. micans (BB in LA & JT in CA)	Biota kills
P. minimum (TB, Ij., Maj. In LA & Forc. in WA)	Toxic
P. sigmoides (BB in LA)	Oxygen depletion
Scrippsiella trochoidea (TB, Ij., Maj. In LA)	Oxygen depletion

Note: (BB) Bar Beach; (JT) James Town; (TB) Takawa Bay; (Forc.) Forcados; (Ij.) Ijora; (Maj.) Majidun; (CA) Calabar Area; (LA) Lagos Area

Source: IAEA (2013)

My research works on phytoplankton revealed them as primary producers of food for zooplankton and other fishes, bioindicators of productivity of the aquatic environments, fisheries production, health, stress, perturbation, pollution and nutrient status of inland waters. **Phytoplankton populations are highly dynamic**, and in many environments they experience episodes of rapid biomass increase (blooms), either as recurrent seasonal events or as higher frequency phenomena.The density and the diversity of phytoplankton are biological indicators for evaluating water quality and the degree of eutrophication (Badsi *et al*., 2012).

- ***Mechanical/Physical Control***

❖ It involves the use of filters, pumps, and barriers (e.g., curtains, floating booms) to remove or exclude HAB cells, dead fish, or other bloom-related materials from impacted waters.

- ***Chemical Control***

❖ It involves the use of chemical or mineral compounds to kill, inhibit or remove HAB cells in the water body.

- ***Biological Control***

❖ It involves the use of organisms or pathogens (e.g., viruses, bacteria, parasites, zooplankton and shellfish) that can kill, lyse, or remove HAB cells.

- ***Mitigation measures***

❖ It involves minimizing HAB impacts on human health, living resources and coastal economies.

❖ Control actions that directly reduce or contain the bloom population such as, checking for warning and closures before harvesting and eating shellfish.

❖ Exercise caution when eating fish caught during HABs by removing the viscera.

Table 23 shows some harmful dinoflagellates in Nigerian coastal and inland waters and their potential harmful effects.

Table 18: Classes and habitats of algae

S/no.	Class	Common Name	Chloroplast Colour	Habitat
1	Euglenophyceae	Euglenoid flagellates	Green/ colourless	Freshwater, brackish, mud
2	Chlorophyceae	Green algae	Green	Freshwater, brackish, marine, terrestrial
3	Bacillariophyceae	Diatoms	Yellow-brown/ dark brown	Freshwater, marine
4	Cyanophyceae/ Cyanobacteria	Blue-green algae	Blue -green	Freshwater, brackish, marine, wet surfaces
5	Cryptophyceae	Crypto falgellates	Green/brown/red/ blue-green	Freshwater
6	Dinophyceae	Dinoflagellates	Colourless/ yellow-green/ yellow-brown	Freshwater, estuaries, marine
7	Xanthophyceae	Yellow-green algae		Freshwater
8	Chrysophyceae	Phytoflagellates	Brown/golden-brown/yellow	Freshwater
9	Prymnesiophyceae	Phytoflagellates	Golden-brown/ yellow	Freshwater, marine
10	Phaeophyceae	Brown algae	Brown	Freshwater, brackish
11	Rhodophyceae	Red algae	Red	Freshwater, brackish
12	Prasinophyceae	Planktonic green algae	Green	Marine

❖ **Factors affecting phytoplankton**

The growth of any plants needs light, carbon dioxide and water for photosynthesis, dissolved mineral nutrients, and a suitable ambient temperature for metabolic activity. For the phytoplankton, water and carbon dioxide may not be problems but sufficient light may be an issue for an organism that has tendency to sink. The followings are the factors affecting phytoplankton:

- ***Light***

Sunlight as the source of radiant energy is a very essential feature of primary production. The means by which phytoplankton cells use the radiant solar energy, the intensity of the incident light, the immediate changes in the light on passing from the atmosphere into water, and the extent to which with increasing depth this light both penetrates and undergoes further alteration. Illumination in all environments depends on the sun's position with latitude and season, time of the day and on the cloud cover. Seasonal light intensity is closely related to temperature.

- ***Chloroplasts (Light-trapping organelle) and Chloroplast pigments***

The chloroplast is the organelle in the phytoplankton cell that traps and uses the sunlight energy to convert carbon dioxide to carbohydrate. It is the organelle system by which energy and carbon dioxide are obtained. Blue-green algae lack discrete cell organelles of a chloroplast nature. There are one or two large chloroplasts per cell in many phytoplankton but in some, for example, certain diatoms, numerous small discoid chloroplasts are present. The efficiency of the chloroplast as a light-trapping organelle is directly related to the surface area it presents to the incident light, and its effectiveness as a photosynthetic structure can be estimated by its output of carbonaceous compounds.

- ***Effect on Socio-economics***

These effects can be divided into four main types:

- ➢ Public Health Impacts
- ➢ Monitoring and Management
- ➢ Recreational and Tourism
- ➢ Commercial Fishery Impacts

- Closure of a body of water or beach due to HAB-related fish kills and toxic aerosols can have substantial effects on tourism and fishing.
- In some cases, the negative public reaction to HAB events can be severe and prolonged, and misinformation can cause scares unnecessarily, creating heavy pressures on management agencies and increasing economic losses.
- Some of the costs are direct, such as those related to health issues and agency monitoring programs, and lost sales of fish and shellfish products. For example in the past decades, U.S has spent more than $1 billion on harmful algal blooms.
- Others may be indirect and harder to quantify, such as negative investment decisions in coastal aquaculture due to the threat of HAB events or lost recreational opportunities.
- The treatment costs for drinking water for industries that depend on clean water only is a major socio-economic effect.

Control measures of HABs

These can be grouped into three categories: mechanical/ physical, chemical and biological control.

Effects of harmful algal blooms

- ***Effects on Fish***

➢ Contamination of sea food products with potent toxins.

➢ Causes mortalities of wild and farmed fish.

➢ Other problems associated with harmful algal blooms are offensive odor and tastes, clogging of fish gills leading to fish kill, poisoning of fish (CEES, 2016).

- ***Effects on Ecology***

➢ Decreased recreational use.

➢ Poor aesthetical value of waters due to toxicity, mats of algae, offensive odor and tastes, and large fluctuation of pH when their cells begin to die (Plate 4).

➢ HABs death and decomposition create dead zones in the water.

- ***Effects on Human and Animal***

➢ HABs have been implicated for man and animal health.

➢ Cyanobacterial blooms can contaminate drinking water with taste, odor, or toxic compounds.

➢ The toxins produced during blooms are possible carcinogens to humans.

➢ Harmful algal blooms have been known for poisoning of man who drinks or baths in ponds with algal bloom.

➢ Waterfowl, livestock and dogs have died after eating mats of cyanobacteria or licking their fur after swimming in bloom infested waters.

➢ Harmful algal blooms can also produce extremely dangerous toxins that can sicken or kill people and animals.

Chloroplast pigments determine the colours of phytoplankton organisms except the blue-green algae. Chlorophyll *a* is the pigment common to all. The other chlorophylls are *b* and *c*; chlorophyll *b* is present only in those with green chloroplasts and chlorophyll *c* are found in a number of brown-coloured organisms. Phytoplankton is classified into two colour groups, green- and brown-coloured. Chlorophylls *b* and *c* differ from Chlorophyll *a* both in molecular structure and their absorption spectra in organic solvents.

- ***Light intensity and spectral quality***

Light intensity and its spectral composition can be limiting to phytoplankton photosynthesis and growth. This is because, in water, there is a gradual decrease in light intensity with depth and the intensity of incident light varying with locality, season and time of the day due to absorption by the water and suspended particulate matter (including the plankton organisms) and reflection by the plankton and other suspended matter. There is also some deflection of light by the water molecules (molecular scattering). The production of organic matter through photosynthesis by any photosynthetic organism will be limited by the breakdown of carbohydrates for respiratory requirements. Where the available light is such that the rate of production of organic compounds equals the rate of respiratory breakdown the compensation point is reached. With phytoplankton, this point is a feature of depth and is the level at which the available light just allows photosynthesis to balance respiratory breakdown. At this depth the production of cell substance ceases.

- ***Plant Nutrients***

The plants nutrients are nitrogen, phosphorus, silicon, other mineral elements (calcium, potassium, sodium, sulphur), trace elements (iron, manganese, copper, zinc, cobalt and molybdenum) and organic substances (carbohydrates, amino-acids, fatty acids, organic acids and vitamins).

Nitrogen and phosphorus: The importance of these two elements in both their effects on plant production and the seasonal changes in phytoplankton must not be underestimated though lack of other elements present in trace amounts can also be limiting to plant production. Potassium appears to be of lesser significance with phytoplankton. Nitrate is an important source of nitrogen source for phytoplankton in both sea and freshwater and is present in much larger amounts in natural waters. Other combined forms of this element are ammonia, nitrite and organic compounds. Phytoplankton convert nitrate to ammonia before assimiliation into cell material so direct uptake of ammonium compounds would be advantageous.

Silicon: Diatoms require silica in soluble form for wall silicification. The silicoflagellates are also dependent on silica foe construction of their tubular skeletons, and scale-bearing flagellates. At times of maximum diatom growth, natural waters show a decline in silica content.

Other mineral substances (calcium, potassium, sodium, sulphur): Calcium seems to be sufficient in concentrations fro phytoplankton requirements in bothe sea and freshwater. Potassium affects phytoplankton growth.

- The main nutrients contributing to eutrophication are phosphorus and nitrogen.
- In the landscape, runoff and soil erosion from fertilized agricultural areas and lawns, erosion from river banks, river beds, land clearing (deforestation), detergent and sewage effluents are the major sources of phosphorus and nitrogen entering water ways (CEES, 2016).

Stable Condition

- Most of blue–green algae prefer stable water conditions with low flows, long retention times, light winds and minimal turbulence; other prefer mixing conditions and turbid environments.
- Drought, water extraction for irrigation, human and stock consumption and the regulation of rivers by weirs and dams all contribute to decreased flows of water in our river systems.

Turbidity

- Turbidity is caused by the presence of suspended particles and organic matter (flocs) in the water column.
- When turbidity is low, more light can penetrate through the water column.
- This creates optimal conditions for algal growth. In return, growing algae create a turbid environment.
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- When turbidity is low, more light can penetrate through the water column.
- This creates optimal conditions for algal growth. In return, growing algae create a turbid environment.

column stratification, nutrient availability, and the intensity and persistence of upwelling conditions.

Light

- Harmful algal blooms absorb light from the sun which increases the temperature of surface water.
- This mechanism further favours the growth of harmful algal blooms and promotes their competitive advantage in aquatic ecosystems.

Salinity

- Certain toxin-producing cyanobacteria are quite salt tolerant, temporary increases in salinity can also cause salt stress leading to leakage of cells and the release of toxins.
- Increases in salinity during drought conditions can also create favorable conditions for the invasion of marine algae into what are usually freshwater ecosystems.

Increase in Atmospheric Carbon Dioxide Concentration

- All algae, including harmful species, require carbon dioxide for photosynthesis.
- Increases in atmospheric carbon dioxide will increase the levels of dissolved carbon dioxide in marine and freshwater ecosystems, favouring those algae that can grow faster in elevated dissolved carbon dioxide conditions.

High Nutrient Load

- Nutrients promote and support the growth of algae and Cyanobacteria.
- The eutrophication (nutrient enrichment) of waterways is considered as a major factor.

Trace elements (minor nutrients)

These are elements required by plants in very small quantities but if present in sufficient supply they may limit phytoplankton growth.

Iron: In freshwater and the sea, iron occurs in particulate matter, in colloidal form, and in solution. The importance of the element to plants is that it is needed as a constituent of vital enzyme systems (such as cytochromes). The quantity in solution in natural waters is always very small, except under acid or reducing conditions in certain freshwater habitats.

Manganese: This element increases the growth of phytoplankton organisms.

Other minor nutrients

These are copper, zinc, cobalt and molybdenum and they are necessary for the growth of phytoplankton.

Organic substances

These are carbohydrates, amino-acids, fatty acids, organic acids and vitamins. They affect phytoplankton growth.

- ***Eutrophic and oligotrophic lakes***

This is a classification based on availability of plant nutrients. Eutrophic lakes have a good supply of nutrients and potentially a high productivity while oligotrophic lakes are opposite. Eutrophic lakes support a rich phytoplankton flora and fauna population. The process of eutrophication can be a long-time enrichment or ageing process in natural waters. Artificial (man-made) eutrophication speeds up this process but sometimes with serious side effects. The nutrient- rich supply in eutrophic lakes can result in dense growth of phytoplankton which significantly reduces light penetration.

- ***Salinity***

Salinity which is the total salt content of water, affects the spatial distribution of phytoplankton organisms. Some are restricted to the freshwater (e.g. the desmids). Inflow of salt water into areas of fresh water will have very harmful effect on the phytoplankton and the principal cause of this is the sodium chloride of seawater.

- ***Top-down or bottom-up forces***

Phytoplankton growth can be controlled by both growth-limiting resources (bottom-up forces) and consumption by herbivores (top-down forces). Periphyton standing crop usually decreases with increase grazing pressure; low or moderate grazing may increase the biomass and stimulate area-specific production by shifting the taxonomic composition of algae.

❖ **Roles and utilizations of phytoplankton**

Hydrobiologists are concerned with phytoplankton within the nanoplankton and ultraplankton categories. Phytoplankton or microalgae do the followings:

- ***Primary/biomass production***

The phytoplankton is the primary source of organic material (**primary production**) in the aquatic environments. Gross primary production is the total fixed carbon (or stored energy) by the phytoplankton. Net primary production is the amount of fixed carbon handed on to the first link (zooplankton) in the food chain after the plants have used some of the organic matter for their respiration. Microalgae synthesize organic matter in aquatic environment. They use photosynthesis to

HABs can invade and occur in freshwater. The impacts of climate change and other sources may promote the growth and dominance of harmful algal blooms through a variety of mechanisms as shown below (Paerl and Otten, 2013).

Other factors

Temperature

- ➢ Harmful algae typically bloom during the warm summer season or when water temperatures are warmer than usual.
- ➢ As temperatures become warmer due to climate change, the growth of harmful algae may be favoured over other non-harmful algae through a combination of mechanisms.

Changes in Rainfall Patterns

- ➢ Extreme rainfall could increase the transport of nutrients from land into water bodies via runoff.
- ➢ If followed by drought conditions as is projected, water bodies may retain those nutrients for longer periods of time, which increases the potential for HAB development.

Sea Level Rise

- ➢ Coastal upwelling is a naturally occurring process, in which alongshore winds move coastal surface water offshore which is replaced by deep water that moves along the ocean floor towards the coast.
- ➢ This “upwelled” water brings nutrients from the ocean floor to the surface leading to high productivity.
- ➢ Harmful algal blooms' growth in upwelling systems vary du to atmospheric oscillations (upwelling or downwelling by interannual fluctuations), and is subject to water-

discolouration off the Light house beach, Lagos (Nwankwo *et al*., 2004) was documented. Blooms of *Anabaena flos-aquae, A. spiroides* (cyanobacteria), *Carataulina bergoni*, *Chaetoceros convolutus, Coscinodiscus centralis* (diatoms) and *Ceratium furca, C. fusus, C. tripos* and *Noctiluca scntillans* (dinoflagellates) have been associated with harmful effects in waters of south-western Nigeria (Onyema, 2008). Adesalu *et al.* (2016) identified some HABs in Oyan dam (Plate 5).

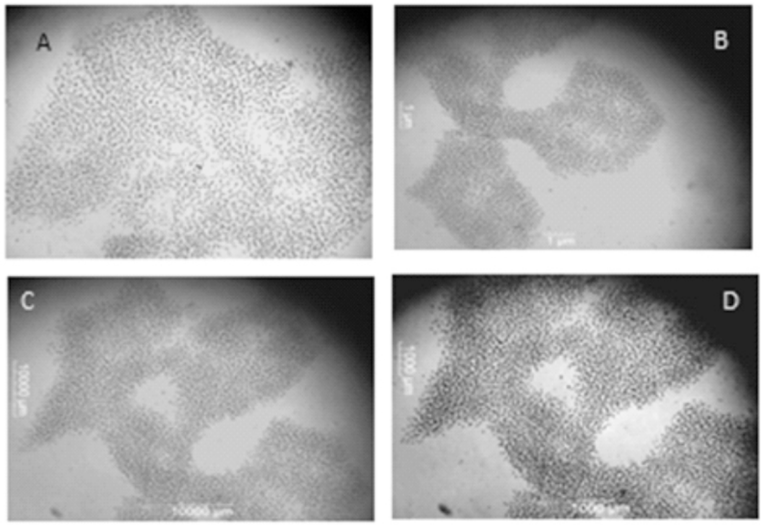

Plate 5: Samples from Oyan dam showing *Microcystis aeruginoca* (Kützing) Kützing (A) and *M. Wesenbergii* (Komarek) Komarek (B to D)

Source: Adesalu *et al.* (2016)

❖ Causes of harmful algal blooms

Climate change is predicted to change many environmental conditions that could affect the natural properties of fresh and marine waters both in the US and worldwide (Paerl and Otten, 2013). Changes in these factors could favour the growth of harmful algal blooms and habitat changes such that marine

build complex carbon molecules just like the land plants. Dissolved nutrients from various sources are absorbed by phytoplankton and in the presence of sunlight (solar energy) and green chlorophylls, combined to produce more complex molecules essential for life and survival.

Microalgae are major contributors to **biomass production** in aquatic bodies (freshwater, brackish and marine). The combine effects of billions of these cells supply most of the plant material consumed by animals (zooplankton and other aquatic organisms) in the food chains and webs. All classes of phytoplankton contribute to primary productivity at varying amount depending on their abundance at the time of measurement. The whole food chains and webs get energy from the biomolecules produced by these microscopic plants. For example, production in the ocean is about 50 grammes and almost all are from phytoplankton photosynthesis. The contribution to energy turnover on the earth is enormous. Annual production of all plant life is estimated at 100×10^{9} metric tons of fixed carbon of which microalgae is a major contributor (Hoff and Snell, 2008). A major contribution to this biomass production comes from the marine phytoplankton. The byproduct of phytoplankton photosynthesis (oxygen) is a very important part of the 'life support' system on earth.

- ***Nutrient recycling, organic buffer and eutrophication control***

Phytoplankton are capable of rapid population growth (grow in order of days) and responsible for nutrient cycling in aquatic habitats. They absorb primary nutrients such as ammonia, urea, nitrates, phosphates and potassium, as well as metals like iron, copper, mangenes, zinc, molybdenum, and vanadium. Some vitamins such as B_{12}, thiamin, and biotin are beneficial to many algae and they are selectively absorbed or produced by some species. Removal and alteration of nutrients by phytoplankton in the ocean is not permanent, since nutrients are slowly being regenerated as microalgae cells die and decay. Other sources of dissolved nutrients are terrestrial runoff, rain, and coastal upwelling. In marine and freshwater aquaria or culture tanks, phytoplankton help to maintain water quality through their removal of excess nutrients and the regulation of pH, that is, each cell is a living **biofilter**.

Phytoplankton are a source of **organic buffer**. They help to balance the pH of aquatic systems by removing excess dissol-ved carbon dioxide and adding dissolved oxygen. They are used to control **eutrophication**, that is, excess nutrients in the aquatic environment. Sewage treatment and water recovery facilities have utilized microalgae to remove primary nutrients. Instant Ocean Hatcheries, a closed-system marine tropical fish hatchery, utilized an outside recovery system consisting of six, ten thousand gallon (38 cubic meters) cement ponds. These were provided with heavy aeration which supported high densities of micro- and macroalgae. Nitrate as high as 30-40 ppm were reduced to 0-5 ppm in three to four months. The inland marine hatchery was able to consistently recover and reuse 70% of total water volume of 110,000 gallons (Snell and Hoff, 2008).

- ***Primary food source (for fish and man)***

Phytoplankton, **pasture of the aquatic bodies** are used as live food for cultured finfish and shellfishes. They are a source of micronutrients, vitamins, oils, and trace

Table 22: Major harmful cyanobacterial bloom-forming genera and their known toxins

Toxin	Detection method(s)	CyanoHAB genera
Aeruginosin	HPLC, MS	*Microcystis*, *Planktothrix*
Anatoxin-a/homoanatoxin-a	ELISA, HPLC, MS	*Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, *Lyngbya*, *Oscillatoria*, *Phormidium*, *Planktothrix*, *Raphidiopsis*, *Woronichinia*
Anatoxin-a(S)	AEIA, MS	*Anabaena*
Aplysiatoxins	MS	*Lyngbya*, *Oscillatoria*, *Schizothrix*
beta-Methylamino-L-alanine (BMAA)	ELISA,HPLC, MS	*Anabaena*, *Aphanizomenon*, *Calothrix*, *Cylindrospermopsis*, *Lyngbya*, *Microcystis*, *Nostoc*, *Nodularia*, *Planktothrix*, *Phormidium*, *Prochlorococcus*, *Scytonema*, *Synechococcus*, *Trichodesmium*
Cyanopeptolin	HPLC, MS	*Anabaena*, *Microcystis*, *Planktothrix*
Cylindrospermopsin	ELISA, HPLC, MS	*Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, *Oscillatoria*, *Raphidiopsis*, *Umezakia*
Jamaicamides	MS	*Lyngbya*
Lyngbyatoxin	HPLC, MS	*Lyngbya*
Microcystin	ELISA, HPLC, MS, PPIA	*Anabaena*, *Anabaenopsis*, *Aphanizomenon*, *Aphanocapsa*, *Cylindrospermopsis*, *Gloeotrichia*, *Hapalosiphon*, *Microcystis*, *Nostoc*, *Oscillatoria*, *Phormidium*, *Planktothrix*, *Pseudoanabaena*, *Synechococcus*, *Woronochinia*
Nodularin	ELISA, HPLC, MS, PPIA	*Nodularia*,
Saxitoxin	ELISA, HPLC, MS	*Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, *Lyngbya*, *Oscillatoria*, *Planktothrix*

AEIA acetylcholine esterase inhibition assay, ELISA enzyme-linked immunosorbent assay, HPLC high-performance liquid chromatography, MS mass spectrometry, PPIA protein phosphatase inhibition assay; **Source:** Paerl and Otten (2013)

Blooms of *Microcystis aureginosa*, *M. flos-aquae* and *M. wesenbergii* have been reported in the Lagos lagoon (Nwankwo, 1993), Ogun river at Iju (Nwankwo, 1993) and kuramo lagoon (Nwankwo *et al.*, 2008), where they caused bluish colouration, anoxia, odour and impacted on the taste of the water (Nwankwo *et al.*, 2003a). Blooms of *Trichodesmium thiebautii* have also been reported off Lagos coast (Nwankwo, 1993) during periods of thermal stratification. More recently a bloom of *Bellerochea malleus* that caused brownish

Bioremediation is a pollution control technology that uses biological systems to catalyze the degradation or transformation of various toxic chemicals to less harmful forms. It primarily employs biological strategies that can be used to clean up the pollutants/contaminants. Bioremediation is a cost effective and efficient method of decontamination that has become increasingly popular in recent times to reduce environmental pollution. Domestic and industrial effluent discharges constitute a major source of water pollution. Removal and recovery of heavy metals from wastewater is important for environmental protection and human health (Kumari *et al.*, 2006).

❖ Harmful algae and harmful algae blooms

Harmful algae are dangerous algae that have the ability to occur in large numbers, in the range of several thousands to millions of cells to form blooms. Harmful algal bloom is the exuberant or abundant growth of dangerous algae. When algal blooms adversely affects aquatic ecosystems or have the potential to affect human or animal health, plants and in the environment they are known as harmful algal blooms (HABs) (Paerl and Otten, 2013). Some species of cyanobacteria, dinoflagellates, red and golden algae have been regarded as HABs. They have the ability to produce potent toxins that can cause adverse health effects to wildlife and humans (Table 22). HABs produce toxins that are classified according to their mode of action into hepatotoxins (e.g. microcystins), neurotoxins (e.g. anatoxins), skin irritants, and other toxins (Paerl and Otten, 2013).

Table 19: Nutrient analysis of six microalgae

SPECIES	***Nannochloropsis***	***Tetraselmus***	***Pavola***	***Isochrysis***	***Thalassiosira***	***Cheatocerus***
Dry weight	18.4%	18.9%	9%	9%	9%	4.5%
Calories/10ml	44.4	48.2%	45+/-	45.5%	22+/-	16.2
Protein	52.11%	54.66%	51.61%	49.69%	50%+/-	27.68%
Protein*	??	30-26%	58-62%	41-47%	??	35.38%
Carbohydrate	16%	18.31%	23%+/-	24.15%	??	23.2%
Carbohydrate*	??	27.06%	15.31%	22.54	??	19.40%
Ash*	??	29.6%	7.4%	8.4%	??	14.7%
LIPIDS	-	---	---	---	---	---
Lipids total	27.64%	14.27%	19.56%	17.07%	??	9.29%
Lipids total*	??	5.12%	15.21%	22.54%	??	??
Omega 3	42.7%	8.1%	23.5%	22.5%	??	??
EPA C20:5*n*3	30.5%	6.4%	13.8%	3.5%	??	??
EPA C20:5*n*3*	31.42%	9.3%	21.00%	2.50%	??	??
DHA C22:6*n*3*	0%	0%	8.20%	10.20	??	??
ARA C18:2*n*6	5.26%	0.40%	??	0.52	??	??
VITAMINS	-	---	---	---	---	---
Vitamin C*	0.85%	0.25%	??	0.4%	??	1.60%
Vitamin C	0.90%	??	??	0.98%	??	1.62%
Chlorophyll A*	0.89%	1.42%	??	0.98%	??	1.04%

Table 19: Contd.

AMINO ACIDS	***Nannochloropsis***	***Tetraselmus***	***Pavola***	***Isochrysis***	***Thalassiosira***	***Cheatocerus***
Aspartic*	9.4%	8.95%	7.27%	10.36%	12.18%	??
Serine*	4.32%	3.71%	3.33%	3.86%	12.18%	??
Glutamic*	15.48%	17.59%	15.47%	11.42%	17.13%	??
Glycine*	7.11%	5.93%	4.75%	6.78%	7.83	??
Histidine*	0.61%	0.19%	0.50%	0.23%	0.43%	??
Arginine*	4.57%	4.59%	4.11%	4.39%	2.83%	??
Threonine*	5.28%	4.40%	3.51%	4.88%	5.38%	??
Alanine*	1.54%	7.62%	5.66%	7.55%	8.57%	??
Proline*	15.12%	6.47%	7.34%	12.48%	8.65%	??
Tyosine*	1.06%	1.84%	1.29%	2.84%	0.60%	??
Valine*	6.90%	5.00%	4.56%	5.49%	5.02%	??
Methionine*	2.64%	2.55%	2.10%	3.79%	2.01%	??
Lysine*	9.07%	8.20%	4.65%	6.96%	7.59%	??
Isolucine*	1.47%	0.97%	0.16%	1.11%	1.78%	??
Leucine*	11.57%	7.94%	7.19%	6.87%	9.21%	??
Phenylaline*	1.92%	3.51%	26.72%	8.25%	1.25%	??
Taurine*	0%	10.55%	0%	0%	0%	??

Source: Snell and Hoff (2008)

remove from water. ***Spirulina*** has been shown to enhance immune system in man, fish, invertebrates and chickens. The National Cancer Institute discovered glycolipids in blue-green algae which are active against the **Human Immunodeficiency Virus** (HIV virus) (Snell and Hoff, 2008). Scientists are now studying how to enhance glycolipids content during the culture of blue-green algae. Many large companies are currently culturing several species of microalgae for pharmaceutical ingredients.

- ***Primary oxygen source***

Phytoplankton are a source of primary oxygen in many low-gradient rivers. Oxygen is the byproduct of photosynthetic activities of phytoplankton.

- ***Bio-monitoring and bio-indicator of pollution***

Phytoplankton are of great importance as biomonitors and bioindicators of pollution. The distribution, abundance, species diversity and species composition of the phytoplankton are used to assess the biological integrity or health of the water body.

- ***Bioremediation of pollution***

Algae are important bioremediation agents being used in wastewater treatment. *Spirulina*, *Chlorella vulgaris*, *Scenedesmus dimorphus*, *Spirogyra sp*, *Cladophora fascicularis*, *Aspergillus niger*, *Anabena flos-aquae*, *Oscillatoria* sp., *Synechococcus* sp., *Nodularia* sp., *Nostoc* sp. and *Cyanothece sp*., *Ascophyllum* and *Sargassum* and other algae have been used as bioremediation agents.

Table 21: Algae species used to raise various invertebrates

Algal species	Aquatic animal cultured
Isochysis galbana-golden-brown, motile, size 4- 8 µ	Rotifers, clams, oysters, conch, sea cucumbers, sea hares (seawater use)
Nannochloropsis oculata- golden-brown, non-motile, size 4- 6 µ	Rorifers, brine shrimps, daphia, monia, marine shrimp (fresh ans saltwater use)
Tetraselmus sp.- green, motile, size 9-10×12-14µ	Rotifers, marine shrimp (saltwater use)
Chlorella vulgaris- green, non-motile, size 2-10µ	Rotifers, protozoans (fresh and saltwater use)
Nitzchia sp- non-motile	Abalones, turbans (seawater use)
Navicula sp-diatom, non-motile	Abalones, turbans (seawater use)
Phaeodactylum tricornutum-diatom, motile, size 3-5×12-35µ	Spiny lobsters, clams, oysters (saltwater use)
Thallasiosira sp.- diatom, non-motile, size 11 - 14 x 14 - 17µ	Clams, oysters, scallops, larval shrimp (seawater use)
Chaetoceros gracillis - diatom, non, size 14×17µ	Clams, oysters, scallops, shrimp, sea urchins, conchs, sea cucumbers (seawater use)

Source: Hoff and Snell (2008)

Combinations of algae species are also used in larval culture of marine shrimps. Marine aquarists use to maintain corals, sponges, barnacles, tube-worms, sea squirts and other filter-feeding invertebrates under culture system.

- ***Source of various products***

Phytoplankton are cultured to produce oils, chemicals, pharmaceuticals and polysaccharides.

- ***Therapeutic effect***

Microalgae have been shown to have therapeutic, antibiotic-like effect on man, fish and other animals. These effects may be attributed to the compounds released by the algae rather than what the algae cells

elements for aquatic communities. They are also rich sources of macronutrients, protein, carbohydrates and especially specific essential fatty acids (Tables 19 and 20). Microalgae provide essential pigments such as astaxanthin, zeaxanthin, chlorophyll, and phycocyanin (the blue pigment) which enhance coloration and health in fish and invertebrates. Microalgae provide primary trace element such as iodine which is essential to almost all living organisms.

Microalgae are directly utilized as human food source far back 600 years by Maya Indians in Central America but now a popular human health food. It is used in cakes and soups, for example, Chad people use it in cakes and soups daily. It is available in powder and pellets. Dried ***Spirulina*** is 65-68% protein and is often used as a supplemental diet for culturing fish, adult artemia and other invertebrates (Snell and Hoff, 2008). An acre of ***Spirulina*** can produce approximately 10 long tons of proteins per year compared to wheat at only 0.16 long tons and beef 0.016 long tons. Annual world production of ***Spirulina*** is greater than 900 tons dry weight, with over 100 tons farmed in USA. At least 40 food manufacturers in USA are currently utilizing ***Spirulina*** as food supplements or ingredients. Products include high-protein drinks, pasta and snacks.

Spirulina, important microalgae

Spirulina (cyanobacteria or blue-green algae) is an example of a commercially important and unique phytoplankton. It is a very complete alga, edible, and provides many health benefits unlike many genera of the cyanobacteria that are harmful to humans. ***Spirulina*** has a very high nutritional value, which allows it to prevent nutrient deficiencies, contains high amount of proteins (50-70%), rich in essential fatty acids, trace elements, minerals, iron (20 times more than wheat germ), magnesium, calcium, phosphorus, potassium, selenium, sodium, and essential amino acids. It is also rich in in Vitamins A, B_1, B_2, B_3, B_6, B_7, B_8 and B_{12}, D, E, K and beta-carotene (provitamin A) and Vitamin B_{12} is 4 times more than raw liver. Essential fatty acids are Omega-6 and large quantity of chlorophyll. Plate 4 shows *Spirulina* tablets.

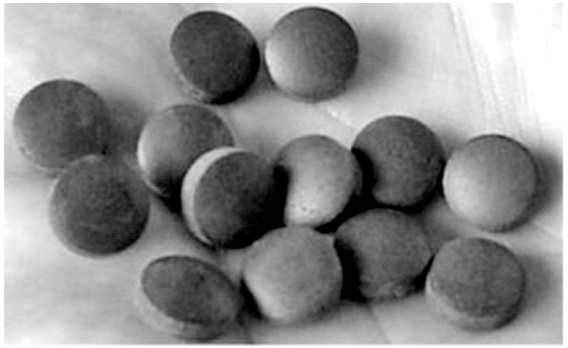

Plate 4: *Spirulina* tablets

Source: http://www.australianspirulina.com.au/spirulina/howtocompare.html

Medicinal properties of *Spirulina*

The medicinal properties of *Spirulina* are as follows:

- **Anti-disease–anti-cancer, disintoxication, powerful antioxidant and anti-aging**

Spirulina helps prevent cancer but not enough studies have been done as of today, but its rich composition provides considerable protection for the body. It is good for the convalescence (synergy with ginseng), stimulates the immune system, reinforces the potential of our immnune defenses, detoxifies the body of heavy metals, pollutants, harmful radiation (synergy with

Chlorella), protection from radiation, effective for combating anemia, reduces high chlolestrol level (frequent usage), protects and reinforces all vital organs, protects from diseases and infections (such as flu, colds, laryngitis, pharyngitis to mention but a few).

- **Enegry-sport-muscles**
- **Balance-stress-memory**
- **Skin-eyes-hair**
- **Cholesterol-diet-Painful and overly frequent periods**

Chlorella and ***Scenedesmus*** are other unicellular microalgae that have become popular as human and animal feed sources. Under semi-controlled growing conditions, the yield of ***Chlorella*** can range between 20 and 60 tons/acre/year with an average of 40 tons. Compared to other conventional terrestrial crops is extraordinary. Averages in tons/year/acre of soybean, 0.5 tons, rice 1.8 tons and alfafa grass 5 tons. The nutritional value of one pound of ***Chlorella*** paste corresponds to 2 pounds of soybean flour. Wet ***Chlorella*** is 80% digestible and dried powder about 65%. A one acre, 3 foot deep pond under continuous culture could conceivably provide enough nutrition to feed 1000 cows per year.

Phytoplankton are utilized as an additive in animal foods and aquarium flake foods. Various live species of microalgae are used as food in the culture of filter-feeding mollusks such as clams, mussels, oysters and scallops (Table 21).