“THEY BOP, THEY SINK: NATURE’S ENERGY CHARGER AND AQUATIC ENVIRONMENTAL PURIFIER”

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An Inaugural Lecture Delivered at the University of Benin

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By

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DEDICATION

This inaugural lecture is dedicated to:
My mother who though saw no four walls of a school sent me to school
My father who gave me love and care
My husband for his wonderful support, understanding and encouragement and
My children, for giving me the inestimable joy of motherhood.
My siblings for the strong bond of love.

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SYNOPSIS

Algae [derived from seaweed “alga” (Latin) and “phykos” (Greek)] are photosynthetic organisms possessing chlorophylls and simple reproductive structures but lacking true root, stems and leaves. They occur in different habitats including extreme ones. Apart from seaweeds, most algae are extremely small culminating in millions of cells in a small volume of water. Ten divisions of algae namely Bacillariophyta (diatoms), Cyanophyta or Cyanobacteria (blue-green algae), Chlorophyta (green algae), Euglenophyta (euglenoids), Chrysophyta (golden-brown algae), Phaeophyta (brown algae), Rhodophyta (red algae), Pyrrhophyta (fire algae, dinoflagellates), Xanthophyta (yellow-green algae) and Cryptophyta (cryptomonads) are commonly recognized.

Algae exhibit different kinds of movements that mimic a dance. Such movements include sliding, gliding, rotation, spinning, gyrating, summersaulting, oscillating, wriggling and flexing of body. Algae, when alive, float on water especially in the euphotic or lit zone, and sink to the bottom of a water body when they die or thrown out of the euphotic zone as a result of turbulence.

The lecture gives a vivid account of the importance of algae, stressing the market or commercial values of products from algae which are multimillion dollar industries in the world. They help in the purification of the aquatic environment via processes such as bioremediation (pollution control), carbondioxide sequestration or removal and wastewater treatment. In addition they have been employed in land reclamation, reforestation, food security, renewable energy, biofuel, medicines, pharmaceutical industries, bioproducts (bioplastics), food, food supplements, fodder, aquaculture feed. They have also been used as biochemicals, global warming antidote, industrial products-phycocolloids (alginates, agar, carrageenan, minerals etc), agriculture (biofertilizer), nanotechnology, environmental studies, cosmetics, nutraceuticals etc.; hence algae can be referred as the HOPE of the PRESENT and FUTURE.

The study of algae (Phycology) in Nigeria started in 1932 and there are still few Phycologists in the country to date.

My researches span classical or fundamental Phycology as well as Applied Phycology. The classical aspect dealt with the taxonomy of certain groups of algae such as diatoms, desmids, euglenoids and chrysophytes among others, indicating their ecological/or biogeographical occurrences, as well as their use as indicators of environmental quality (in environmental monitoring). In Applied Phycology, my research addressed the use of algae in bioremediation-clean-up of pollutants such as industrial effluents, heavy metals etc. Studies with hydrocarbons (from different sources such as aromatics, petroleum, crude oil and refined petroleum products) revealed growth stimulation at low concentrations (0-50%) and inhibition at higher concentrations, the threshold being 50%.

Environmental assessments of some water bodies in Edo State revealed that some water bodies, especially in Akoko-Edo were hard waters and dominated by euglenoids or blue-green algae, while others were soft water, comprising predominantly green algae and diatoms.

A study on the use of algae in Long-term monitoring of English Lakes District using algae showed that some lakes remained constant in their nutrient levels, while some have changed for the better (from higher level to lower level) or worse (from lower to higher levels).

The lecture also lists some harmful algae in Nigerian coastal waters of Nigeria and some freshwater environments. Niger Delta studies showed the influence of salinity on the distribution of algae on the one hand, and the preponderance of diatoms on the order, epitomizing the brackish nature of the environment.

The study of the only warm and unique spring (Ikogosi Warm & Cold) in Southern Nigeria showed that both springs differed markedly physically, chemically and phycologically.

Algal biomass production studied in both the natural environment and the laboratory showed that whereas algal production in the natural environment was enhanced in the dry season, laboratory investigations revealed that organic fertilizer, in particular, poultry dung, supported the greatest biomass.

A new technique on the response to environmental change by algae was developed and tested in both natural or field and laboratory situations/conditions.

Numerous algae were listed as new records in Nigeria, West Africa and Africa while a new species to science was reported.

The recommendations made include setting up of “Algal Culture Collection Center”; Algal herbariums”, at the University of Benin; extraction, use and commercialization of algal products as well as vigorous pursuit and exploitation of algae as an alternative source of renewable energy.

INTRODUCTION

This is about the third inaugural lecture delivered in the subject area in the country- First was Opute (1990) on “The Botanical Frontier: With Periscope on The Nigerian Coastal Environment” at the University of Benin and the second was by Nwankwo (2004) on “The Microalgae: Our Indispensible Allies in Aquatic Monitoring and Biodiversity Sustainability” at the University of Lagos. This inaugural lecture also marks the first inaugural lecture to be delivered by the first Nigerian female Phycologist. It also represents the first inaugural lecture to be given by a woman at the Faculty of Science in the forty year’s history of the University of Benin.

They Bop, They Sink, What are They?

They are algae. The word ‘Algae’ is derived from the Latin word “alga” meaning sea weed; Greek word for algae is “phykos” also meaning sea weed. The study of algae is called Algology or Phycology and a person who studies algae is therefore called an Algologist or a Phycologist.

Algae are photosynthetic organisms possessing chlorophylls and simple reproductive structures but lacking true root, stems and leaves. Algae lack embryo and their reproductive structures have no surrounding protective layers of sterile cells. They have been variously described as ‘pond scum’, ‘grass of the sea’, ‘sea vegetable’ etc.

They are found in different habitats. Algae are cosmopolitan, occurring in nearly all habitats including terrestrial(soils), aerial, aquatic (freshwater (rivers, lakes, streams), brackishwater, marine-oceans) environments, on and within other plants and animals, rocks/stones (epilithic), mud, sand (episamic) in desert, hot springs on snow or ice. They form associations such as lichens (algal-fungal associations), algal-coral association and algal-sponges association. They are also found in fossil record as far back as three billion years (Precambrian). They are quite diverse from very minute forms to giant forms called kelps. They can be single celled, colonial, filamentous, parenchymatous (boxy), pseudoparenchymatous (woven filaments to give boxy shape) and siphonous (tubular).

Size: Algae vary in shape and size; ranging from small single-celled type (0.2

micron or picoplankton) to complex and giant form like the kelps which can grow to 100 meters in length. Apart from the seaweeds which comprise about 3550 species, a vast majority of algae (total about 30,000 species) are very small and are invisible to the naked eye. On the basis of size, algae can be grouped into the following categories:

0.2-2µm Picoplankton
2-20 µm Nannoplankton
20-200 µm Microplankton
200-2mm Mesoplankton
>2mm Macroplankton

Therefore 1 ml of water can contain millions of algae.

Blue-green algae were the first plants to produce oxygen on earth. Without them there would be no life on earth.

Algae are commonly held in culture collection centers (as live or herbarium specimens).

Classification

Algae occur in a wide array of forms. Ten divisions or groups are commonly recognized. These are Bacillariophyta (diatoms), Cyanophyta or Cyanobacteria (blue-green algae), Chlorophyta (green algae), Euglenophyta (euglenoids), Chrysophyta (golden-brown algae), Phaeophyta (brown algae), Rhodophyta (red algae), Pyrrhophyta (fire algae, dinoflagellates), Xanthophyta (yellow-green algae) and Cryptophyta (cryptomonads). Of all of these, cyanobacteria are prokaryotes while all others are eukaryotes. Recently, researchers believe that blue-green algae should not be included amongst algae.

Sea weeds

Seaweeds are larger attached multicellular algae growing in the shallow areas or bottom of the sea or brackishwater. They are of three different types- according to the wavelength absorbed and consequent colours of red, brown (Kelps) and green. There are green (about 1200 species), brown (about 1750 species) or red (about 6000 species) [Guiry, 2009].

Seaweeds have several uses eg medicinal, fertilizer, food and industrial. Industrial application of seaweeds is hinged on extraction of phycocolloids and biochemicals. They are used in cosmetics (facial, body and hair products), processed foods such as chocolate milk, yoghurts, health drinks, and even the highest-quality German beers (Guiry, 2009).

How Do Algae Bop & Sink?

Bop means to dance to music characterized by complex harmony and rhythms. Algae exhibit different kinds of movements. They are enigmatic and graceful in those movements. For instance, there are different types of movements such as sliding (e.g blue-greens), gliding (e.g diatoms), rotation (e.g *Micrasterias thomassiana* var. *rotata*), spinning (e.g dinoflagellates), gyrating (e.g Volvocales), summersaulting (e.g *Gonium*), oscillating (e.g *Oscillatoria*), wriggling (e.g blue-greens) and flexing of body and changing of body shape called Euglenoid motion (e.g *Euglena*)

In fact *Volvox,* according to a recent research by Cambridge University scientists (Drescher *et al.*, 2009) is said to have two "dance steps" called "waltz" and minuet". In the "waltz", two colonies orbit each other as in a planet circling the sun while in "minuet" the colonies oscillate back and forth, as if held together by an elastic band. Algae can dance around each other in stable groups joined together in the surrounding water, only by fluid flows they create. The lead author of the research- Professor Raymond E. Goldstein- a Professor of Complex Physical Systems concluded "These striking and unexpected results remind us not only of the grace and beauty of life, but also that remarkable phenomena can emerge from very simple ingredients."

Algae require light for photosynthesis and in an aquatic ecosystem, light diminishes with depth. So in a given aquatic environment, algae must stay within the lit zone called the euphotic zone (the depth of which vary from water body to water body) and must remain afloat for them to successfully carry out their biochemical activities especially photosynthesis. In the euphotic zone, algae float, move sideways and up and down as if they are dancing. Free-floating algae are specifically termed phytoplankton. Several factors help algae to keep afloat and these include size, gas vacuole, flagella, mucilage secretion, accumulation of fats and oils and shape (eg flat, cylindrical, coiled, needle-like, horns). Algae will sink when they die or when turbulence sends them out of the lit or euphotic zone.

ECONOMIC IMPORTANCE OF ALGAE

Algae are important in several ways, grouped as beneficial and deleterious:

BENEFICIAL EFFECTS

1. **Food for humans**.

Seaweeds and certain other algae have been an important source of food for people especially of coastal countries such as Korea, Japan and China. About 1-3 million tons of seaweeds per annum are produced by 30 countries around the world. In China, Japan and Korea, seaweed production for human consumption constitute a multimillion dollar industry. The most commonly exploited algae include, *Porphyra*(nori), *Ulva, Chlorella, Nostoc, Monostroma, Caulerpa, Undaria*(Wakame), *Laminaria* (Kombu or Kunbu) *and Spirulina.* These algae are used as important ingredient for soups and also as spices for flavouring meat. They are rich in protein, organic mineral nutrients, vitamin B (such as niacin (Vitamin B), C, folic acid (Vitamin C) and inorganic iodine. Iodine is a precursor for thyroxin. These minerals are important in a well balanced diet. *Rhodymenia palmata* (Linnaeus) Kuntze, common name: dulse is a red alga which is dried and may be bought in the shops in Ireland. It is eaten raw, fresh or dried, or cooked like spinach. The red alga *Porphyra* (common name: purple laver), is also collected and used in a variety of ways eg; bread, jelly in the British Isles and in wrapping 'sushi' in Japan; in Wales, it is mixed with oatmeal and bacon fat to make laver bread. Algae are commercially cultivated as a nutritional supplement eg. *Spirulina platensis* is low in fats, calories and is cholesterol-free and thus used as health food; it aids immune system activity as well as cardiovascular health. It is a comprehensive source of rich and unique nutrients such as proteins, essential amino acids, gamma linolenic acid (GLA), alpha linolenic acid (ALA), linolenic acid (LA), stearidonic acid, arachidonic acid (AA), eicosapentanoic acid (EPA), eicosadienoic acid (EDA), vitamins B_1, B_2, B_3, B_6, B_9, B_{12}, C, D, & E, potassium, calcium, copper, iron, manganese, magnesium, phosphorus, sodium, selenium, zinc and chromium. This alga is frequently harvested for food in Chad, Egypt and Mexico. Other algal species cultivated for their nutritional value include; *Chlorella* (a green alga), and *Dunaliella salina*, which is high in beta-carotene and is used in vitamin C supplements.

The oils from some algae have high levels of unsaturated fatty acids. Arachidonic acid (a polyunsaturated fatty acid), is very high in the green alga *Parietochloris incisa* and in diatoms.

2. **Fodder**

The brown algae- *Ascophyllum nodusum, Laminaria and Fucus* are used as feed supplement for animals. These algae supply the animals with a wide range of vitamins, inorganic minerals and trace elements. This practice is very common in France and Ireland. U.K is the largest producer of livestock feed from seaweeds. Algae are also used as aquaculture (fish, oysters, clams etc) feed.

3. **Role in primary production**

Algae play a great role in the complex web of life as the main primary producers in aquatic environments. They are the foundation of food chain/web in aquatic ecosystems. Algal metabolism and productivity are critical to the natural flora and fauna of these habitats. They help to replenish the oxygen balance of the atmosphere.

4. **Minerals & Elements**

The brown sea weeds known as kelps are a rich source of soda, potash, iodine and alginic acid. When carefully processed, they can also yield substantial quantities of ammonia and tar or charcoal. Seaweeds are rich in trace elements such as copper, zinc, iron, cobalt, vanadium, molybdenum, manganese, boron and chromium. Japan contributes 5-7 % of the world production of iodine (from kelps). Iodine is the most important component of thyroid hormone and thus has large application in the chemotherapy of thyroids. The high iodine-yielding Phaeophyta are used in the treatment of goiter as well. Organic beta-carotene is produced from *Dunaliella salina* in Australia (Guiry, 2009).

Industrial gum: Industrial gum is extracted from seaweed and is of three types: Alginates, Agar and Carrageenan. They are called phycocolloids

5. **Alginates**

Alginates are colloidal products or salts of alginic acid found in the cell wall of Phaeophyta e.g. *Fucus, Laminaria and Macrocystis.* They are heteroploysaccharides comprising blocks of guluronic and manuronic acids which are the constituents of cell wall of Phaeophyta (brown algae). Alginates/alginic acid comprise 20-30% of total dry matter of brown sea weeds (Bruton *et al.* 2009). Examples of kelps with exploitable quantities of alginates include Laminariales and Fucales such as *Macrocystis pyrifera, Laminaria hyperborea, L. digitata, Saccharina japonica, Ascophyllum* *nodosum, Ecklonia* and *Durvillea.* Alginates are used in making flame-proof fabrics. Plastic materials of alginates are used extensively in dental impressions, gauze for internal operations etc. due to their non-toxicity and colloidal properties, alginates have a number of applications in the preparation of commercial products for public consumption such as soups, sauces, ice creams other dairy products, shaving creams and antibiotic capsules. They are used for thickening, suspending, stabilizing gel, in cosmetics to prevent cream from crystallizing; in the production of film, rubber, and linoleum. They are also used in textile industries and as emulsifying agents in the preparation of polishes and paints.

Alginate (Sodium alginate) is used as an emulsifier and/or a stabilizer, in textile industries, ice-creams and dairy products. The insolubility of calcium alginate in water has resulted in production of fibres which could be used in bandages, textiles/textile parts, fire-proof clothing. Calcium alginate (beads) is also used in immobilization of cells or delivering of certain chemicals as well as encapsulation of natural juices of fruits.

The main alginate producers are China, USA, Norway and Scotland while Japan, Chile and France produce smaller amounts. The production of 15,000 tonnes of alginates nets a value of $120 million (Guiry, 2009).

6. Agar-agar & Carrageenan

Cell wall of red seaweeds contains large quantities of agar and carrageenan which form strong gel in water and are therefore called hydrocolloids. Usually, a given seaweed contain either or carrageenan but not both. Examples of agar-containing alga is *Gelidium* and carrageenan-containing alga is *Eucheuma.*

Agar-agar often called agar is a jelly-like, amorphous, colloidal and translucent material (phycocolloid) that is packaged in granules, flakes, bricks, or sheets. It is a complex polysaccharide of great economic value. Agar is prepared by boiling the algae in water, after which the filtered solution is cooled, purified, and dried. It is used as a microbiological medium for growth of microorganisms like fungi, algae, bacteria and other tissues. It was used to cultivate tuberculosis bacterium for the first time. It is also used in making confections, as a stabilizer or emulsifier in food, cosmetics, leather and pharmaceutical industries. Agar is used in the canning of fish and meat, in textile and paper industries. Medically, it is used as an inert carrier of drugs in medicine, and is often administered as a laxative and is sometimes prescribed for the treatment of prolapsed (sagging) stomach.

Agar is produced from seaweeds. The major genera producing agar are *Gelidium, Gelidiella, Ahnfeltiopsis, Pterocladia* and *Pterocladiella.* Agar of highest quality is found in red algae in the family Gelidiaceae while agar of lower quality comes from other families, Graciliaceae in particular. The production is valued at $100 million and more, producing countries including, Japan, China, Canada, France, Indonesia, Mexico, Madagascar, Morocco, Namibia, Russia, New Zealand, South Africa, Peru, Chile, Portugal, Indonesia, Spain, Thailand and United States of America (Guiry, 2009).

Agarose fraction of agar (found only in certain red seaweeds) is used in many biotechnological applications of DNA research and gel electrophoresis.

Carrageenan: These are polysaccharides made of D –galactopyranose units only extracted from some algae. They are used as food additives for stabilization, thickening and gelation. They have emulsifying and gelling properties. Carageenan is used as a thickening and stabilizing agent in puddings and shampoos, for the stiffening of milk and dairy products, such as ice cream. It also finds uses in instant puddings and sauces.
They are used in dairy products, especially milk proteins where it prevents the fractionation of milk constituents. It is very famous in making chocolate milk. It is used in enhancing ice creams, chocolate milk, cheese, custards, jellies, confectionery, meat and protein drinks (Guiry 2009). They are used as a lubricant, reducing friction in sensitive areas, possess antiviral and anti-microbial properties, and employed as an effective carrier for anti-retroviral drugs in HIV prevention and treatment (Guiry 2009). Examples of carrageenan-producing algae include *Eucheuma, Kappaphycus, Chondrus*, *Furcellaria*, *Gigartina*, *Sarcothalia*, *Mazzaella*, *Iridaea*, *Mastocarpus* and *Tichocarpus.* Countries that are the main producers of carrageenan include USA, France, Philippines and Denmark while Ireland produces much less. In 2007/2008, Carrageenan production exceeded 50,000 tonnes equivalent to value of over US$600 million (not including China) (Guiry, 2009).

7. Fertilizers/Growth substances/Biochemicals

Seaweeds are naturally rich in chemicals such as potassium, phosphorus, trace elements and growth substances. They are extensively used as manure. Certain forms like blue-green algae can maintain and regulate the nitrogen budget of ecosystems. Some species of cyanobacteria can turn atmospheric nitrogen into ammonia, a form that can then be used by plants as a nutrient. Farmers in tropical countries grow cyanobacteria in their flooded rice paddies to provide more nitrogen to the rice, increasing productivity as much as tenfold.

Some seaweeds contain high levels of growth hormones such as auxins and cytokinnins. Similarly, residue obtained from processing sea weed for useful products can be used as bio-stimulants in agriculture, horticulture and even aquaculture. Some of the liquid extracts of brown seaweeds contain in addition, active substances which act as pesticides against common pests and have therefore been used in agriculture and aquaculture. Such products include Maxicrop, Alginure, Algea, Seasol and Seagro. They enhance plant growth conferring additional benefits of increasing crop yield, resistance of frost, increased inorganic nutrients uptake from soil, fruit storage loss minimization and general increased resistance to environmental stress.

8. Soil Reclamation

Saline and alkaline wastelands can be reclaimed using blue-green algae (Madal *et al.* 1999). These algae prefer alkaline pH, water-logging and high humidity. The cultivation of blue-green algae in such environments results in decreased pH, increased nitrogen, phosphorus and organic matter content of the soil thereby converting it to a fertile and arable land with time. Thus algae, especially blue-green ones are applied in the rejuvenation of saline and alkaline soils.

9. Diatomite (Diatomaceous Earth)

When a diatom cell dies, its silica cell wall remains intact and this accumulates over time to form a powdery like compound called diatomite or diatomaceous earth. Large deposits of diatomite occur in both freshwater and marine environments. Diatomite is extremely porous and insoluble and is therefore useful in filter and for oils for clearing solvents, liquid absorbents, most industrial filtration devices, bleaching agents, abrasive powder for cleaning and polishing metals. It is also used in wine and paper industries. It is light weight and fire proof hence used as a thermal insulator (in insulation and in preparation of high temperature furnaces). It is uses as fine abrasive in detergents, tooth paste making etc. It is also used as a mechanical insecticide in insect pest control, in polishes, paper products, sound proofing products and construction and as component of dynamite. Diatomaceous earth makes a good polisher for fine surfaces

10. Antibiotics

Microalgae show antibiotic, antiviral activities and have been screened for, and isolation of pharmacologically active compounds, antineoplastic (anticancer) compounds, antibiotics, many with novel structures, several of which may find application in veterinary and human medicine or agriculture (Borowitzka, 1995).

Some algae have been reported to produce antibiotics effective against many pathogenic bacteria. E.g the first pharmaceutical antibiotic invented from algae is Chlorellin and is produced by *Chlorella vulgaris* and it is effective against gram negative and gram positive bacteria including *Staphylococcus aureus, S. pyogenes, Bacillus* etc. Extracts from *Chladophora, Lyngbya* etc have been used to kill strains of *Pseudomonas and Mycobacterium* and exhibit antiviral activities as well. Some red algae produce some sulphated polysaccharides which show antiviral activities towards viruses responsible for some human infections such as herpes, possible treatment of tumors, lung cancer etc (Smit, 2004). A red marine alga (*Corallina officinalis* effective against *Enterobacter aerogenea* ; green alga (*Ulva rigida*) and some brown algae (*Dictyota dichotoma, Cystoseira barbata* etc) are effective against *Staphilococcus aureus* (Taskin *et al.* 2007) Certain Cyanophyta and Characeae have been claimed to have larvicidal properties since very few mosquito larvae occur in waters supporting growth of such algae. Marine algae have also been shown antibacterial activities to pathogenic bacteria (Taskin *et al.*, 2007)

11. Sewage and Effluent Treatment:

This is one of the applications of algae in Industrial Ecology whereby waste products are turned into useful materials. Growth of algae in sewage/effluents results in increased biomass production in addition to the oxygen released.

Algae are used to treat effluents/sewage pumped through the ponds called Sewage oxidation ponds. In such ponds are grown unicellular algae such as *Chlorella, Chlamydomonas, Scenedesmus* and *Euglena.* The algae through the process of photosynthesis produce oxygen which is used by bacteria for the decomposition of the sewage. Additionally, the algae use up minerals in the sewage. Sheraton Hotel(s) Ikeja, Lagos utilizes sewage oxidation ponds in the treatment of domestic effluents.

The treatment of sewage is important because (a) it has an offensive odour (b) sewage water is very rich in inorganic nutrients like sulphur, nitrogen and phosphorus (c) has numerous microorganisms.

12. Dye making

There is much interest in the food industry into replacing the synthetic colouring with natural dyes. In this regards, dyes from algae pigments in particular carotenoids (yellow β-carotene; orange to yellow xanthophylls such as astaxanthin and canthaxanthin obtained from some green microalgae *Dunaliella salina and D.bardawil*) and red/blue dye from phycobilins are currently used (Arad & Sepharim, 1998). Astaxanthin is a potent antioxidant and *Haematococcus pluvialis* is a major natural source of astaxanthin. Dyes can be obtained from algae such as seaweeds. Thus natural pigments produced by algae can be used as an alternative to chemical colouring agents and dyes. It is thought that inks made from algae are much easier to break down and recycling can be possible.

13. Algae as Antidote to Global warming: Greenhouse gas (Carbon dioxide) Sequestration

The use of marine algae as CO_2 sinks has been canvassed (Ritschard, 1992). The use of algae in carbondioxide sequestration in power plants is one of the contemporary topics in algal application. Algae described as the grasses of the sea act as a sink for carbondioxide which they fix during photosynthesis while at the same time release oxygen to make the earth habitable.

Algae use carbon dioxide, the most implicated green house gas responsible for global warming, as raw material for the process of photosynthesis.

Research has established that algae absorb 50% of the world's carbondioxide (John, 1994). Thus algae can/may save the planet from global warming. Through this carbon dioxide sequestration, algae can reduce greenhouse gas emissions at power plants. Therefore algae can provide the much needed antidote for global warming. Algae Bioreactors have been constructed and attached to power plants to trap the emitted carbon dioxide thereby preventing its release into the atmosphere. The carbondioxide results in increased algal growth or biomass which can be harvested for food, fodder, fisheries, fertilizer or other purposes

14. Algae & their role in Bioremediation

Bioremediation is the application of biological treatment in the removal of contaminants from the environment. Specifically, bioremediation by algae is termed phycoremediation.

Phycoremediation offers several advantages/benefits (Sivasubramanian, 2009) in comparison with other bioremediation agents. These include:

- The algae used do not produce toxic products since they are not pathogenic.
- Provide oxygenation of the systems through photosynthesis thereby enabling effective decomposition
- Reduction in carbon dioxide concentration (green house gas)
- It is a safe, cost-effective and ecofriendly process
- Phycoremediation reduces nutrient load and consequently total dissolved solids effectively as these are used up during photosynthesis
- Produces high algal biomass which can be used as live feed in aquaculture and as biofertilizer.
- Phycoremediation detoxifies and removes toxic wastes.
- Simple operation and maintenance
- Potential for energy and nutrient recovery
- Cost of construction and operation are less than half of those of mechanical treatment plants (eg activated sludge, sequencing batch reactors,)

15. Brewing:

Irish moss (a red alga, *Chondrus crispus*), is used by brewers as a fining agent (make smaller molecules aggregate into larger particles so that they settle out of solution). The addition of Irish moss to the wort 15 minutes before the end of the boil produces a clearer beer.

16. Pollution control

The application of algae in pollution control include:

- Algae are used in wastewater treatment facilities thereby reducing the need for more dangerous chemicals use.
- Algae can be used to trap fertilizers in runoff from farms. These algae are subsequently then harvested, and can they themselves can be used as fertilizer.

- Algae bioreactors are used by some industrial power plants to reduce carbon dioxide emission. To achieve this, the carbon dioxide can be pumped into a pond, tank, in which the algae are grown.

17. Role of algae as Environmental Monitors

Different types of algae are indicative of different environments. For instance desmids inhabit clean, oligotrophic (nutrient-poor), un-polluted water bodies while euglenoids and blue-green algae are reminiscent of polluted and/or eutrophic (nutrient-rich) water bodies.

18. Bioplastics

Algae are recently being considered for biodegradable Bioplastics production (Asada *et al* 1998).

19. Medicinal Phycology (Medical Aspects of Phycology)

a) Biomedical products

Many microalgae are natural sources of bioactive molecules as they are capable of producing structurally complex molecules which are otherwise difficult or impossible to synthesize chemically (Borowitzska, 1995). Many seaweeds contain natural products with curative potency against disease-causing bacteria and other parasites e.g *Chondria armata, Digenia simplex* and *Sargassum* spp are used in the treatment of common intestinal worm, *Ascaris lumbricoides*

Algae have been used for a long time, especially in Asian countries, for their purported powers to cure or prevent illnesses as varied as cough, gout, gallstones, goiter, hypertension, and diarrhoea. Recently, algae have been surveyed for anticancer compounds, with several cyanobacteria appearing to contain promising candidates. Many Cyanobacteria have been shown to produce antiviral and antineoplastic compounds (Borowitzka, 1995).

Diatoms are also used in forensic medicine as the presence of diatoms in the lungs of a dead person indicates that the person died from drowning.

b) Treatment of Cancer

Seaweeds have been claimed to be used as antimutagenic agents –breast cancer (Teas, 1981), Leukemia (Yamamoto *et al.* 1984). Extract from a red alga, *Amphiroa zonata* was found to exhibit strong cytotoxicity to all human leukemic cells tested (Harada & Kamei, 1997).

c) Bone Tissue Engineering: Calcareous marine algae are used as a source of ceramics for bone tissues engineering. Eg *Corallina* is being used in bone-replacement therapy. Stein & Borden (1984) provide an extensive review.

d) Algotherapy: Refers to the use of algae such as seaweed in facials, body wraps, and baths for rejuvenation and detoxification of human body. *Fucus serratus* is used in France and Ireland for the production of seaweed extract for cosmetics and for seaweed bath (Guiry, 2009).

e) *Chondrus crispus* (a red seaweed) is used for treating respiratory disorders (influenza, cold and tuberculosis (Guiry, 2009).

f) According to Mschigeni (1993), some algae are used as aphrodisiac (i.e promoting male virility). E.g *Eucheuma isiforme* is used in the Caribbean Island and *Porphyra* is used in Philippines.

20. Scientific Research Materials

Algae are a veritable resource in various scientific researches such as biotechnology, environmental studies, nanotechnology (nanomaterial science & nanomaterial engineering) etc. An example of study in nanotechnology is re-creating the silicate chemistry of nature by chemical methods: artificial synthesis of hollow cell walls of diatoms by Japanese scientists. They have been used in elucidating the biochemical pathways of many metabolic reactions. Their small size and frequency of division have helped in these studies.

21. Algae As Alternative Source Of Energy

The use of algae in biofuels production is not new. Their utilization started in around 1940s but attention was not seriously paid to it because of cheap barrel of oil. With the astronomical rise of cost of oil to a record high of $150pb in 2008, people began to seriously reconsider using algae again.

A comparison of oil from algae with that from other crops shows that algae have more oil relative to other plants (Table 1).

Table 1: Comparison of some sources of biodiesel (Chisti, 2007)

Crop	**Oil yield (L/ha)**	**Land area needed (Million ha)**
Corn	172	1540
Soybean	446	594
Canola	1190	223
Jatropha	1892	140
Coconut	2689	99
Oil Palm	5950	45
Microalgae	58,700-136,900	2-4.5

The world demand for energy is growing on daily basis. To meet this demand, it will require a myriad of energy sources. Algae have been considered as potentials for next generation and renewable fuels. They have been regarded as one of the most promising candidate or source of biofuel production among the bio-feedstock currently being explored.

In recent times, emphasis has shifted to exploring algae as biocrude or for biofuel. Algae have been variously described as the 'green solution' to world's energy problem, "next generation of biofuel", "the ultimate in renewable energy", "the biofuel of the future", "potentials for next generation and renewable fuels", "the most promising candidate or source of biofuel production among the bio-feedstock currently being explored".

Algae are generally favourable as biofuel feed stock because of their high photosynthetic efficiency, lipid productivity coupled with their rapid reproductive rate.

Elsewhere, especially in advanced countries, several companies have been looking at the possibility of extracting biofuel from algae, turning their attention to developing biofuels from algae that will be compatible with today's gasoline and diesel fuels. Biodiesel, bioethanol, biomethanol and even biogas can be produced from algae. The use of algae will not compete with economic or food crops like corn, soybean, oil palm etc.

There are very many strains of algae, producing differing ratios of the three main types of storage food compounds: oils, carbohydrates and proteins. Those high in carbohydrates as well as oils produce starches that can be separated and fermented into ethanol; the remaining proteins can be turned

into animal grains.
Some of the countries in which biofuel is already being produced from algae include New Zealand, Israel, Japan, Spain, Netherland, Ireland in Europe, Australia, United States of America, , Canada and Argentina among others.

Some of the reasons why alternative sources of energy should be vigorously considered and pursued include:

1) The rising and unstable cost of petroleum-based energy in the world market
2) The dwindling petroleum reserves in the world
3) The restiveness in the oil-producing areas of the world
4) Exacerbated environmental problems
5) Non-renewability of petroleum as against the renewability of other sources

Algal Biomass for Biodiesel production has gained prominence in many places.
Use of algae /Algae-based technologies have the following advantages:

a) Cleaner technology- Key tool for reducing greenhouse gas emissions from power plants and other carbon intensive industrial processes.
b) Rapid reproduction rate.-They grow and can multiply quickly (hours, days, weeks)
c) Use up less space than conventional crops
d) Produce food for fish, livestock and humans
e) Greater yield of oil than other crops ("algae produce oil and can generate 15 times more oil per acre than other plants used for biofuels, such as corn and switch grass" APA 2008)
f) Lack of competition with traditional food crops [They are not used in this part of the world for food]
g) They can be cultivated everywhere in any part of the country. They can grow in desert, in wasteland, in polluted waters (waste waters) and compete with no freshwater. They can grow in brackish waters as well.
h) They do not compete for arable land. -They can be grown in water and lands not suitable for crops
i) Large scale production is possible
j) Raw materials are available, cheap and inexhaustible
k) Algae can and are already being used in a wide variety of industries and applications, and as such a wide range of end-uses enable companies to produce both fuels and non-fuel products from the same algae feedstock. An algal biorefinery could produce multiple products such as oils, protein, and carbohydrates.

In view of the advantages enumerated above, algae are currently emerging as the preferred biomass feed stock for global biofuel industry.

In tropical regions like Nigeria, the mass production of algal biomass is very promising in view of the abundant sunlight as well as favourable temperatures throughout the year.

Interestingly,

a) *Even polluted waters can be used to grow pollution-tolerant forms by so doing, abate pollution and achieve the desired goal of biomass production and consequent biodiesel production.*
b) *The residue from oil extraction can be used as animal feed*

In exploring alternative source of energy, it is imperative to divest from sources of energy that compete with the human stomach as this can thwart the much cherished global food security. Algae are the answer. Also the use of algae which grow everywhere, in every country, will minimize the explosive geopolitics surrounding petroleum crude oil.

Types of Energy from Algae

Different types of energy can be produced from algae. These include biodiesel, bioethanol, biogas and thermal and electricity (Chisti, 2007, 2008, Schenk *et al.*, 2008)):

a. Biofuels production: Algae are a rich source of biofuel. They can produce oil naturally. Algal biocrude from raw algae can be processed to make gasoline, diesel and jet fuel. Algae are important feedstocks because of higher oil yield, their widespread availability, among other characteristics.

b. Bioethanol/Methanol: Species of algae capable of producing more carbohydrates and less oil are processed by various methods to make different products. Eg ethanol by fermentation, methanol by anaerobic digestion, while the leftover proteins are used as animal feed (GreenFuel Technologies Corporation, based in Cambridge, MA.)

c. Biogas (Hydrogen) production: Hydrogen can be produced from algae by gasification. Algae can naturally produce hydrogen under certain prevailing conditions. For instance If the algal culture medium is deprived of sulfur it will switch from the production of oxygen (normal photosynthesis), to the production of hydrogen, via the activities of the hydrogenase enzyme. Also, the addition of copper result in hydrogen production from algae *Chlamydomonas reinhardtii and Chlamydomonas moeweesi* are good sources of hydrogen production.

d. Electricity & Thermal Energy: Biomass from algae can be burned to produce heat and electricity.

22. Commercial values of algal Products

According to Radmer (1996), purified phycobiliproteins (from red seaweeds) sell for about $5000/g in a modest $2 million market. Also the combined market value of hydrocolloid (carrageenans, agars & alginates) is put at approximately $500 million. Others are as follows (Table 2):

Table 2. **Commercial or market values of some algal products**

Product	**Use**	**Market Value (million $ US)**
Spirulina	Food	80
Beta-Carotene	Nutritional Supplement	25
Chlorella	Food	100
Labelled Compound	Growth media	5

DELETERIOUS EFFECTS

1. **Toxicity & Parasitism**

Toxic algae such as some species of *Microscystis, Dinophysis, Gymodinium etc* cause mortality of fish and other animals. Endotoxins produced by some algae accumulate in the glands of animals drinking infested waters and can result in paralysis and death. Some of the toxins produced include paraletic shell poisoning, diurhetic shell poisoning, okadaic acid, domoic acid, mycrocystin etc
Effect on aquatic animals

Algae can cause death of animals in the aquatic ecosystems via oxygen depletion, physically by choking and by release of noxious compounds.

2. **Biofouling**

Algae can grow on anything defacing it. Eg car, window louvers, metal framework, walls of houses, steel etc.

Seaweeds may grow on the metal hulls and woodwork of ships and boats producing a fouling, corroding and destructive effect. A thick growth of seaweeds sometimes results in considerable increase in friction between hull and water, thereby increasing the wear and tear and reducing the life span of the vessel.

3. **Municipal water supplies**

Algae produce effects which directly or indirectly are associated with their growth. These include:

- loss of recreational (aesthetic, swimming) and fishing values: this can result from excessive growth of *Microcystis, Spirogyra, Cladophora, Pithophora*
- imparting taste and odour by metabolic or decomposition products of nuisance organisms eg *Synura, Synedra, Asterionella, Anabaena, Microcystis, Dinobryon*
- clogging of water filters thereby reducing filter runs
- interference with purification of water
- alteration of the chemical composition of water via changes in pH, CO_2, bicarbonates and oxygen content of water

4. **Spoilage of the quality of commercial products of food, pharmaceutical and pulp industries.**

5. **Corrosion of concrete and metallic walls of pipes and boilers** by carbonic, oxalic and silicic acids excreted by certain algae eg *Anacystis, Cladophora.*

Harmful Algae/Algal Bloom or “Red tide”

Algal bloom is a dense aggregation of algae/phytoplankton in an aquatic environment. Algal bloom phenomenon has been colloquially called "Red tide". This is a misnomer because algal blooms can produce different coloration, not necessarily red, depending on the species causing it. Secondly, blooms are not associated with tides.

Of the numerous algae existing, a few species are known to cause negative impacts on the aquatic environments, damage to other organisms through the production of toxins. Most often than not, these are very common amongst the dinoflagellates, diatoms and blue-green algae. Sometimes these algae proliferate to form what is known as harmful algal bloom (HAB). They are caused by natural processes (upwelling relaxation, circulation, river flow, storms, currents) and anthropogenic loadings culminating in eutrophication (Sellner *et al.* 2002), transportation of toxic species via ballast water and introduction of industrial and sewage effluents to coastal waters (Anderson 2009); environmental change typified by sunlight, nutrients, water quality, temperature, etc; global shipping; absence of grazers as well as dispersal by ocean and wind currents. Harmful algae are algae capable of producing a variety of deleterious effects. Harmful algal bloom have dire consequences such as social impacts (tourism, recreation, aesthetics), economic impacts (aquaculture-fish kill, shell fish loss, increased drinking water treatment costs, hydroelectric power generation), health impacts, ecosystems impacts (habitat loss, alteration of food web interaction), ecological (anoxia), wildlife mortalities (birds, whales, dolphins, turtles etc), trophic level impact (accumulation and transfer of toxins along the food chain).

Of harmful algae, some produce potent toxins called phycotoxins (Takahashi *et al.* 2007)) culminating in the respective syndromes termed Neurotoxic Shellfish Poisoning (NSP), Paralytic Shellfish Poisoning (PSP), Ciguatera Fish Poisoning (CFP), Diurrhetic Shellfish Poisoning (DSP) and Amnesic Shellfish Poisoning (ASP). Such toxins include brevitoxin responsible for NSP, saxitoxin for PSP, ciguatoxin and maitotoxin for CFP, okadaic acid, pectenotoxin, yessotoxin and dinophysistoxin for DSP and domoic acid for ASP (de Charon *et al.* 2001). The consumption of toxin-contaminated food by humans can lead to grave health fatalities manifested in symptoms such as death, allergy, dermatological, respiratory, cardiovascular problems, liver damage, gastrointestinal and neurological disorders typified by headache, diarrhoea, vomiting, abdominal pains, seizures, short term amnesia, sweating, paralysis and coma (van Dolah 2000).

Non-toxic algae can produce biomass-related harm especially during bloom formation.

Do we have harmful algae in Nigerian waters?

YES!!!

Examples of harmful algae (Plate 1) identified in Nigerian coastal waters (Kadiri 1999d, 2002, 2009) include:

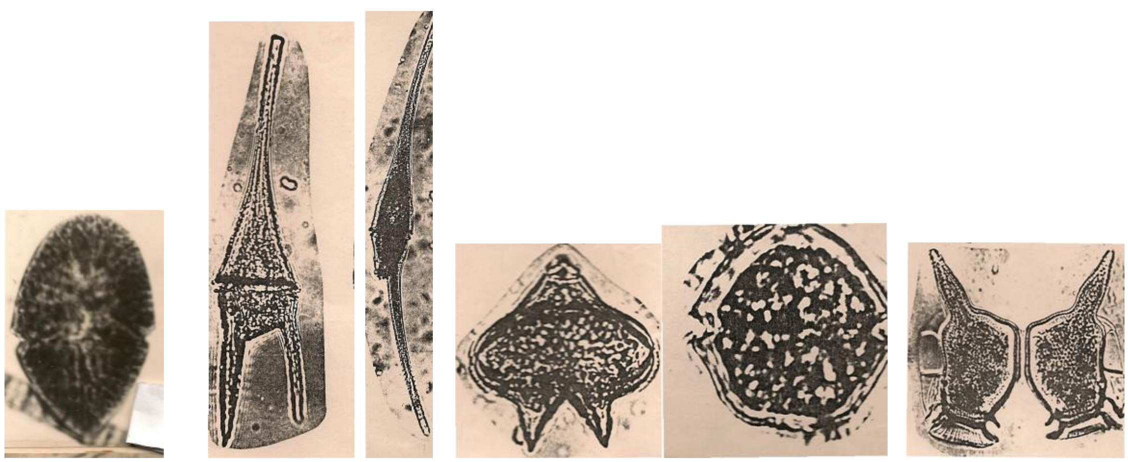
Bacillariophyta (Diatoms)
Chaetoceros convolutus

Cyanophyta (Blue-green algae)
Microcystis aeruginosa
M. wassenbergii
Anabaena spiroides

Dinophyta (Dinoflagellates)
Dinophysis caudata
Gymnodinium fuscum
Peridinium gatuense
Protoperidinium mite
Prorocentrum micans
Ceratium furca
C. fusus
C. tripos

Some cyanobacteria harmful algal bloom species in freshwater include:

Anabaena circinalis
Anabaena flos-aquae
Aphanizomenon flos-aquae
Cylindrospermosis raciborskii
Microcystis aeruginosa



Gymnodinium fuscum   *Ceratium furca*   *Ceratium fusus*   *Protoperidinium mite*   *Peridinium gatuense*   *Dinophysis caudata*

Plate 1. Some Examples of toxin-producing algae in Nigerian coastal waters (Photos courtesy of Professor F.I. Opute).

HISTORY OF PHYCOLOGY IN NIGERIA

The knowledge about algae is traceable to over two thousand years ago but the study of Phycology started in the last three hundred years. The first reference to algae in history dates back to 3000 BC when an emperor of China used them as food (Huisman, 2000). The red algae *Porphyra* was used as food in 533-44 A.D (Mumfard and Miura, 1988)
Significant progress in the study of algae was only made following the discovery of microscope in 1600. In the 17th century, the first Australian marine plant was collected from Shark Bay (Huisman, 2000).

In 1936, the first alga, a diatom was photographed and studied with Scanning Electron Microscope. Thereafter, other divisions of algae have also been studied using SEM. This microscope x-rays the micromorphology of the algae. It serves to confirm minute characters.

In Nigeria, the study of Phycology dates back to 1932 when Mills collected diatoms from Warri. Fox (1957) also studied marine algae from Lagos to Port-Harcourt and Hendey (1958) on diatoms of Tarquah Bay. Early phycological investigations existing elsewhere, in the northern Nigeria is River Sokoto (Holden & Green, 1960), in the western axis of the country include reports of Imevbore (1965, 1967, 1968)- Eleyeile reservoir; Egborge (1973, 1974) on River Oshun and Nwankwo (1988) in Lagos Lagoon complex. We made our debut in phycology in the eighties.

The Nigerian Phycologist: An Endangered Species

In general, phycologists are an endangered species in Nigeria. There are not more than 20 in the country. This means that very many universities are without Phycologists. Consequent upon this, very many aquatic environments or water bodies in the country are left unexplored phycologically. This implies that a lot of opportunities exist in the field for upcoming researchers.

My Phycological Foray

How I found my way into Botany

As a very young girl of 18 I gained admission to the University of Lagos where at that time, admission was open eg we were admitted into Faculty of Science to read any course eg Physics, Chemistry, Zoology, Botany, mathematics etc. I loved physical sciences –Physics and Mathematics in particular. As I was confused and deciding which course to go into, an elderly white man approached me and asked me what my problem was. I told him I was confused and was trying to decide what Department I should go into and he replied that I should go to Department of Botany and I complied. I found out later that he was the head of Department of Botany. Little did I know that they were shopping for students. Well I accepted my fate and graduated as the Best graduating student.

As a Phycologist

In the early eighties, environmental issues began to take center stage in the world and realizing the critical role of algae in environmental assessments, Professor Opute encouraged me to study Phycology. I thank God so far that I have always made the best out of every situation I found myself. I have enjoyed every aspect of the course ever since.

MY CONTRIBUTION:

I will attempt to address my multifarious and divergent researches in the subject of Phycology.
Bibliography on West African & African Algae (Kadiri 1992, 2004): Earlier bibliography of African Algae was done by four English men (Brook, Kufferath, Ross & Sims (1957)

1) Taxonomy/Ecology/Biogeography of Algae

In my career, I have carried out taxonomic studies on desmids, diatoms, Euglenoids, Chrysophytes among others. The taxonomic materials obtained are valuable identification materials for present and future studies of algae in Nigeria.

Desmids

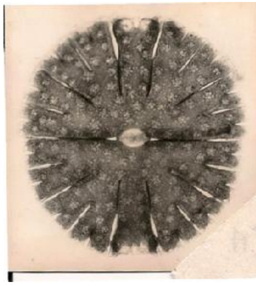
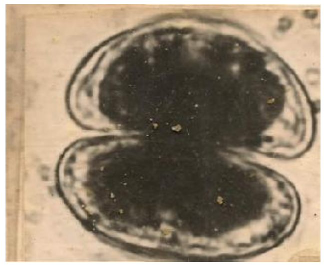
Desmids are a group of unicellular, microscopic green algae (Chlorophyta) belonging to the order Zygnematales and families Desmidiaceae and Mesotaeniaceae. They mostly inhabit freshwater (but not exclusively), acidic,

nutrient-poor water bodies.
Desmids have attracted the attention of microscopists for a long time because of:

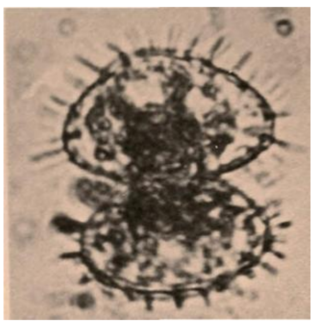
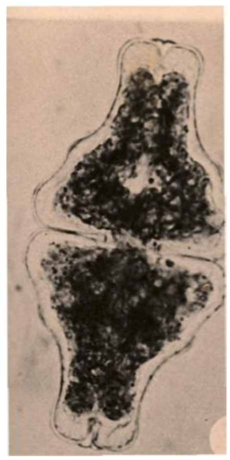
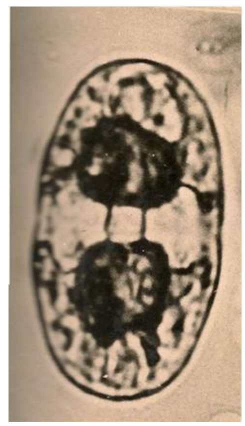
a) Their exquisite shape
b) Unique symmetry
c) Intriguing cell division and sexual reproduction pattern
d) Their use as indicators of special aquatic environment and water quality.

Desmids are very beautiful algae and have visually impressive (very attractive) shapes. They are generally of two types-those that are symmetrical comprising two semicells which are mirror images with a narrow connection or median incision termed isthmus, referred to as true or placoderm desmids (Desmidiaceae) and those with no constriction of wall into two semicells termed 'false' or saccoderm desmids (Mesotaeniaceae). The cell wall of true desmids has 2-3 layers with numerous pores while that of false desmids has only one layer without pores.
Desmids are recognized as important group of organisms in the classification of freshwaters and in the topology of lakes, in the assessment of the conservation value of aquatic habitats (Coesel, 2001; Krasznai *et al* 2008) and in the assessment of freshwater quality and bioindicators of trophic status (Ngearnpat & Peerapornpisal, 2007).
Kadiri (1988) studied and documented 39 taxa of *Closterium,*(Plate 2) out of which 33 were first record in Nigeria
In 1989, Kadiri & Opute reported a rich flora of *Micrasterias,* 17 of which were previously unrecorded in Nigeria. The preponderance of desmids in the aquatic ecosystems studied is believed to be related to the low ionic strength and mildly acidic nature of the Ikpoba reservoir.
Kadiri (1993a) identified 28 taxa of *Cosmarium*, 25 of which were new record for Nigeria. In another study, Kadiri (1993b) presented a taxonomic details of 24 baculiform desmids (plate 2) belonging to the genera *Pleurotaenium, Gonatozygon,Groenbladia, Penium, Hyalotheca, Cylindrocystis, Tetmemorus* and *Spirotaenium.* Only three of these were previously identified in Nigeria. The distributional occurrences of these algae in Africa were documented.

Kadiri (1993c) also recorded 28 taxa of *Actinotaenium, Arthrodesmus, Euastrum, Staurastrum* and *Staurodesmus,* (plate 2) twenty -two of which were new record for Nigeria. Their African occurrences or biogeography were also shown.


Micrasteria thomassiana var. *notata* *Cosmarium depressum var planctonicum* *Staurodesmus curvatus* var. *latus*

Staurastrum gladiosum *Euastrum didelta* *Actinotaenium mooreanum*




Closterium incurvum *C. parvulum* *Spirotaenium condensata* *Desmidium baileyi*

Plate 2. Some desmids species

Diatoms

Nature's wonderful architecture is displayed in this group of algae. Diatoms are a group of algae with exquisitely beautiful silica cell wall called frustule. They belong to the division Bacillariophyta. Diatom cell wall has ornamentations of fine ridges, pits, pores and lines or striations, which are either radially (Centrales) or bilaterally (Pennales) arranged along the axis. Some of the colonial forms have three dimensional shapes. Diatoms are most abundant in marine environments, also present in freshwater environments (lakes, rivers) as well as terrestrial environments. Diatoms have an extensive fossil record; consequently can provide important information on past environmental conditions (palaeoenvironmental bioindicators). They are used in monitoring of environmental conditions and water quality (Round, 1991).

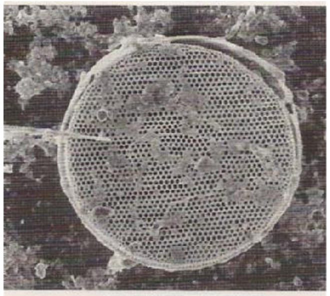
Kadiri & Opute (2003) applied Scanning electron microscopy at Institute of Freshwater Ecology, England to the study of diatoms from the Ikpoba reservoir and documented 18 taxa belonging to the genera *Cymbella, Stenopterobia, Brachysira, Eunotia, Frustulia, Navicula, Pinnularia, Stauroneis* and *Surirella* (Plate 4). The occurrences, distribution and frequency of these taxa were indicated. The diatoms were compared with national and regional records. The species of diatoms found are reminiscent of acid, nutrient-poor environments, implying that they are good indicators in the event of future alteration in the Ikpoba Reservoir.

Elsewhere in the south-south part of Nigeria, Kadiri (2003) documented 15 taxa of diatoms including their ecology, distribution in Nigeria and West Africa. The diatoms were four taxa of *Odontella,* three of *Aulacosira,* two of *Chaetoceros,* and one of *Pleurosigma, Asterionella, bacteriastum, Surirella* and *Coscinodiscus.* This work was carried out at the University of Zurich, Switzerland.

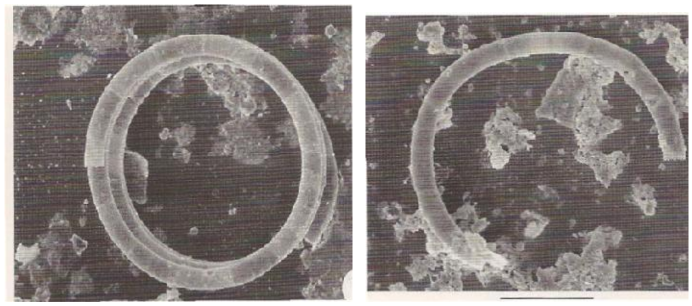
Kadiri (2007a) with the aid of a Scanning Electron Microscope at the University of California, Berkeley, U.S.A., provided an annotated taxonomic account of more diatoms from the Niger Delta Area of Nigeria. These belong to the families Coscinodiscaceae, Melosiraceae, Heliopeltaceae, Eupodiscaceae and Surirellaceae and genera *Coscinodiscus,* (plate 3 *Stephanodiscus, Actinoptichus, Triceratium* and *Surirella* (Plate 5) and records were compared with national, sub-regional records of Nigeria, West Africa, Africa as well as world oceans.

The overall scientific contributions of all taxonomic studies are:

a. They provide resource materials for future taxonomic studies
b. Useful for fisheries
c. The data obtained on the structure and composition will be helpful in the assessment of the aquatic resources and subsequent management

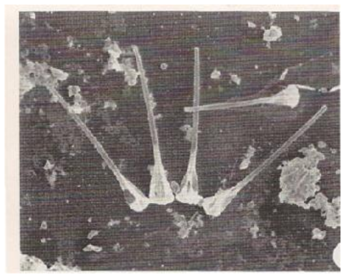


Coscinodiscus lineatus

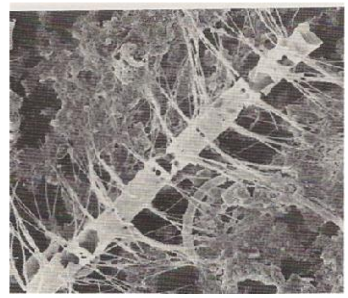


A. granulata var. *angustissima* f. *curvata*

A.*granulata* var. *angustissima* *f. spiralis*

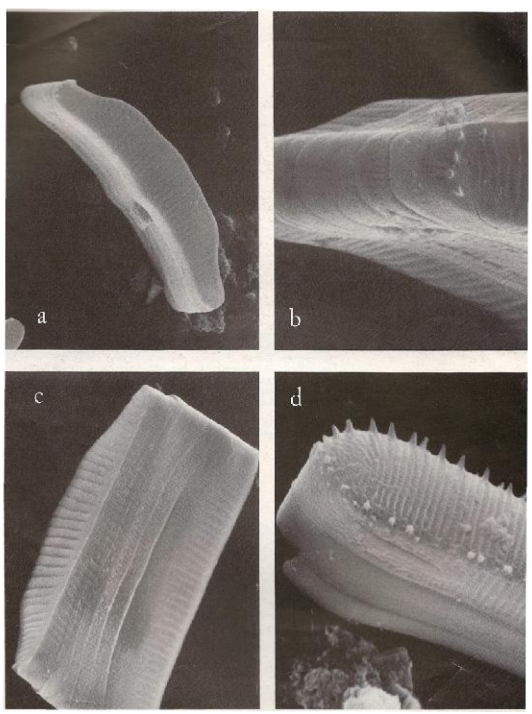


Asterionella glacialis

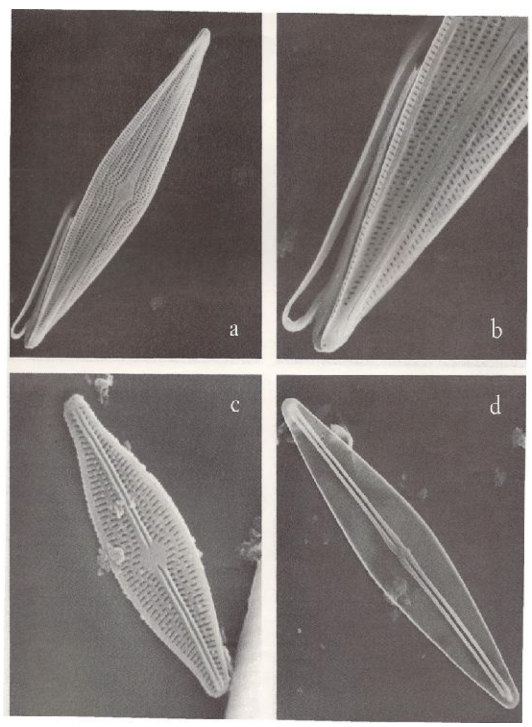


Chaetoceros eibenii

Plate 3. Some diatoms (Centric forms)

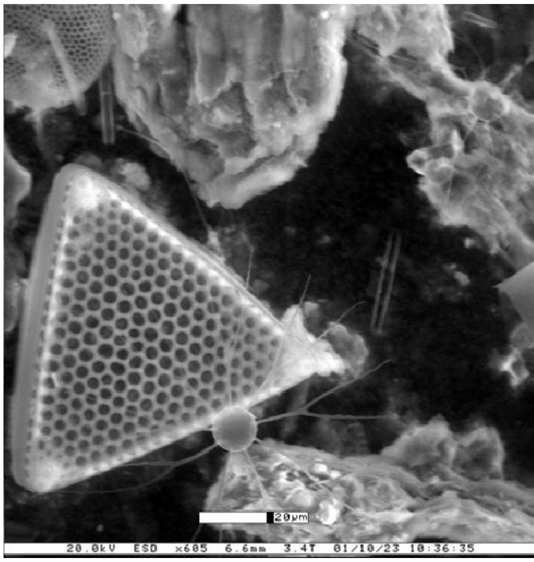


a-d *Eunotia garusica*



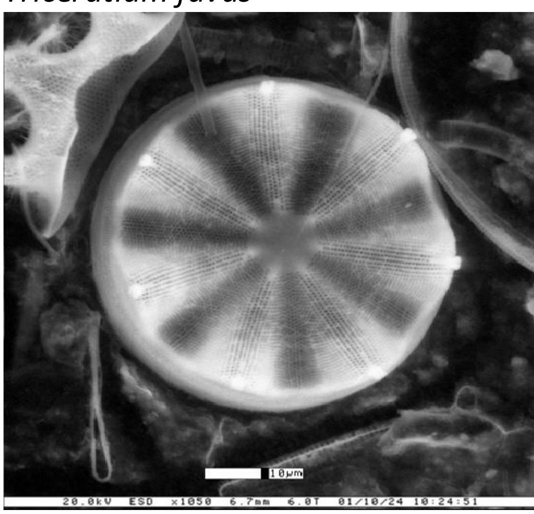
a,b: Brachysira serians, c: Brachysira, d: Frustulia rhomboides

Plate 4. Some diatom species (Pennate forms)

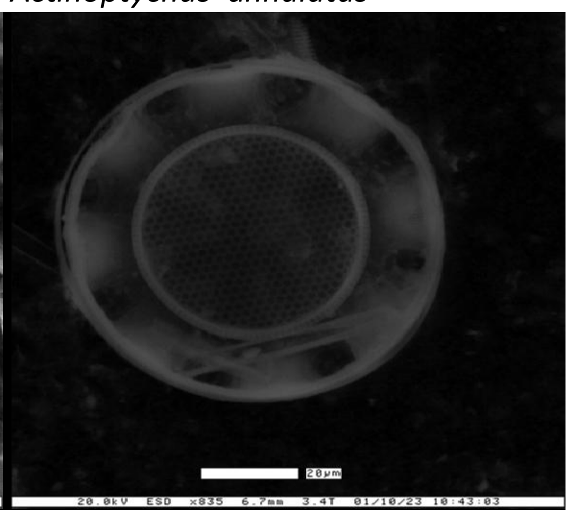


Triceratium favus

Actinoptychus annulatus



Actinoptychus bifrons



Coscinodiscus cf commutatus

Plate 5. Some diatom species (Centric forms)

Euglenoids

Euglenoids are members of the division Euglenophyta. They are known for or unique in their characteristic undulating shape-changing motion called metaboly, elastic pellicle, plant and animal features. Euglenoids thrive very well under eutrophic conditions or high nutrient levels and are therefore used as bioindicators of eutrophication/pollution (Tripathi, & Shukla, 1993).

Kadiri & Opute (2000) examined the euglenoids (Plate 6) of the Ikpoba Reservoir and reported 22 taxa belonging to four genera of *Euglena* (12)*, Leplocinclis* (1)*, Phacus*(7) *and Trachelomonas*(2). The African biogeographical records of the species were indicated.

Phacus longicauda

Euglena oxyuris

Trachelomonas superba

Lepocinclis playfairiana

Plate 6. Some examples of euglenoids from Ikpoba Resrvoir

Chrysophytes

Chrysophytes are golden algae with rigid cell wall made of silica found mostly in freshwater but also in marine environments. Their golden colour is due to a pigment called fucoxanthin.

Chrysophytes are only next to diatoms as indicators of environmental conditions. They are known to characterize slightly acidic, soft water of low conductivity, alkalinity and conductivity (Smol, 1995).

The Nigerian Chrysophytes are poorly documented.

Based on Transmission and Scanning Electron Microscopy, at Central Michigan University, U.S.A, Wujek, Kadiri & Dziedzic (2010) reported a total of 19 silica-scaled chrysophytes (Chrysophyceae: one species each in *Chrysosphaerella*, *Spiniferomonas*, and *Paraphysomonas*; Synurophyceae: 11 *Mallomonas* spp. and five *Synura* spp.) (Plate 7) from some rivers in Benin, Nigeria, over a period of 12 months in 2003. Seven are new records for Nigeria, including six new African records.

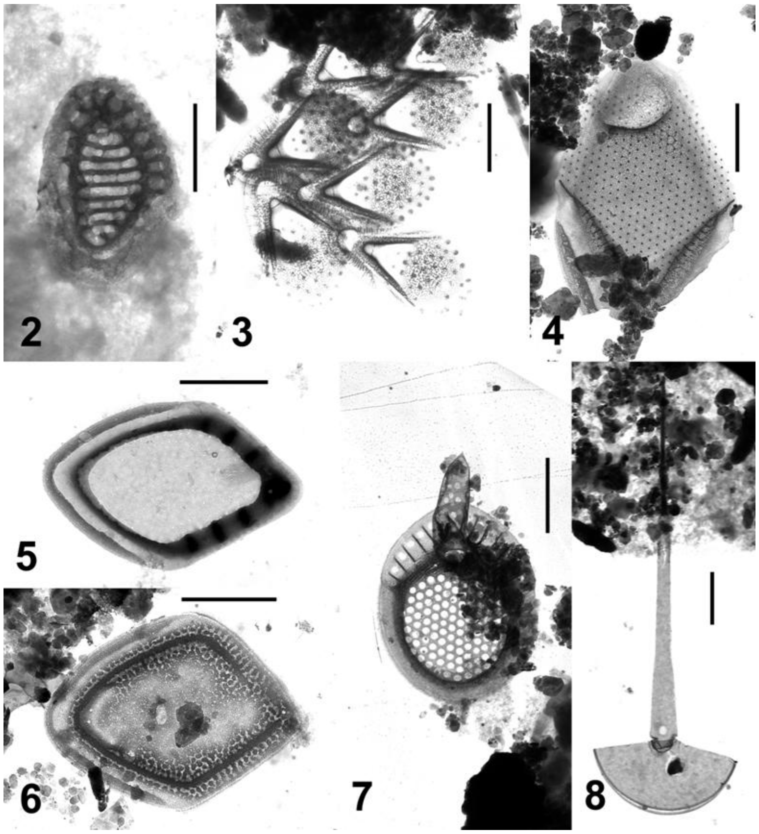


Plate 7.Chrysophytes from some Rivers in Edo State [Fig 2.*Mallomonas doignonii* var. *doignonii*: 3. *M. parvula*: 4. *M. paxillata*: 5. *Mallomonas* sp. 3: 6. *Mallomonas* sp. 4. Fig. 7. *Synura leptorrhabda*: Fig. 8. *Spiniferomonas septispina]*

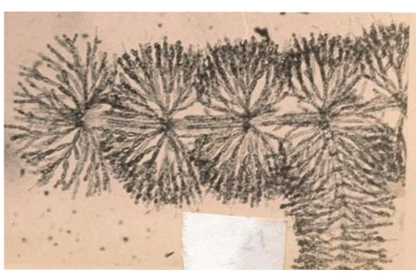
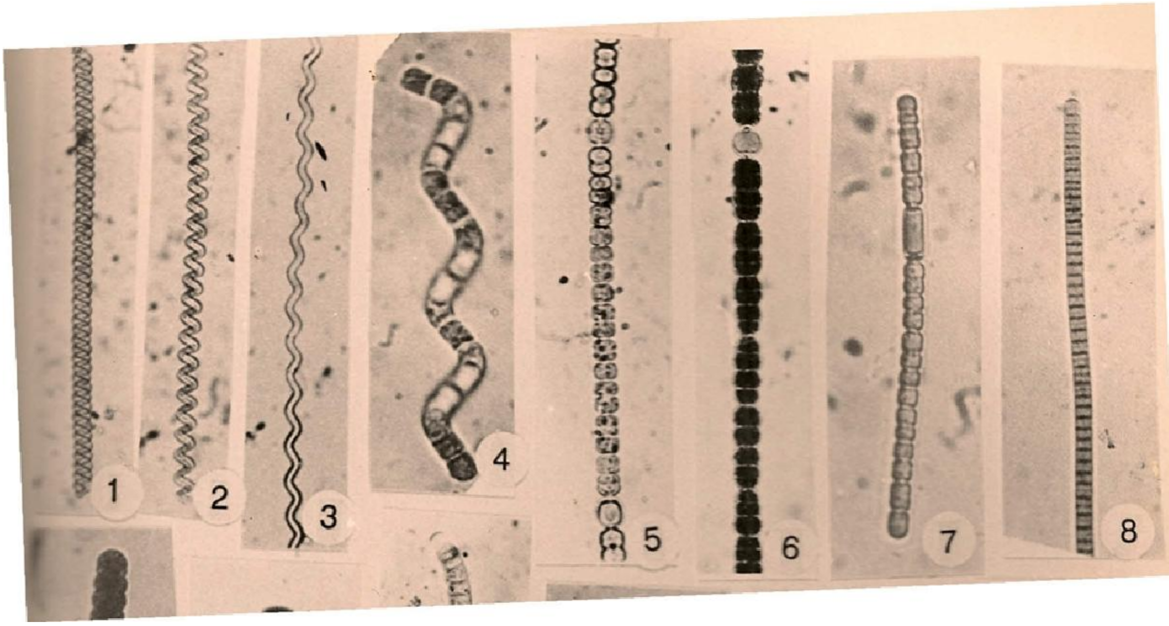
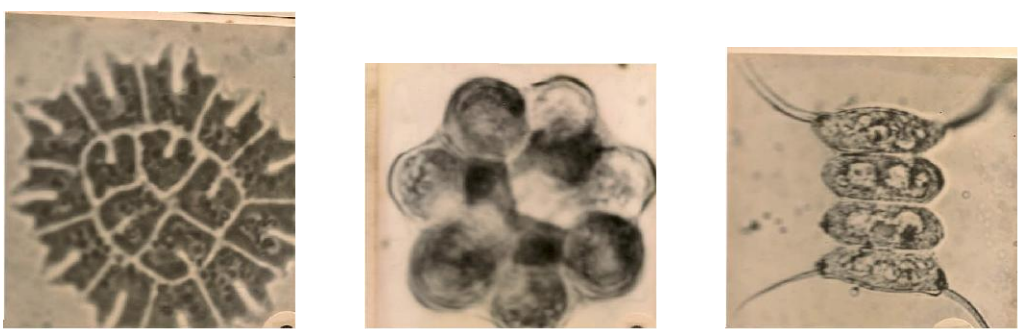


Plate 8.*Batrachospermum vagum*
(One of the few freshwater examples of Red algae)



1. *Spirulina labyrinthiformis* 2. *S. major* 3. *S. albida* 4. *S. aeruginea*
5. *Anabaena6. A. affinis* 7. *A. alatospora* 8. *Oscillatoria bornettia*

Plate 9a. Examples of Blue-green algae from Ikpoba Reservoir



Pediastrum tetras *Coelastrum recticulatum* *Scenedesmus quadricauda*
Plate 9b. Examples of Green algae from Ikpoba Reservoir

2) Environmental Assessment (Water quality studies –Limnology)

Studies of Some springs streams in Edo State

Most small water bodies hardly get studied. Worst still are those in remote areas. Yet these water bodies very important because they are:

a) Sources of drinking water and other domestic activities
b) Sources of proteins
c) Sources of human parasites such as guinea worm, bilharzias etc

A study (Kadiri, 2001) of some springs in Edo north, specifically Akoko Edo area (Osu, Wagbafeleme, Urumena all in Somorika; Ifege in Igarra and Makeke), showed that Makeke and Osu are hard water springs and rich in ions particularly sodium, calcium, chloride and somewhat magnesium ions whereas, Ifege, Wagbafelemi and Urumena springs are soft water springs and consequently low in these ions. Most of the springs were high in silicate. Generally, the springs were slightly acidic to neutral (pH 5.6 -7.3).

On the biological aspect, 90 taxa of phytoplankton were collected and identified. Osu spring was noted for blue-green algae, Wagbafeleme mainly green algae, comprising unicellular forms, in particular desmids, and colonial forms notably *Scenedesmus* spp. Ifege was notable for blue-greens and a red alga, Urumena for diatoms and Makeke mainly euglenoids in addition to some blue-greens and diatoms.

Five springs were investigated in Etsako-West, Owan-West and Esan-Central (Kadiri, 1999b). They were Omemhi, Oki, Uhumoke, Igbidin and Jordan. These springs though generally low in nutrients were essentially bicarbonate waters with moderate chloride levels and high silicate content. As sources of drinking water, the springs satisfy the World Health Organisation guidelines in most parameters, except for pH, iron and turbidity. All streams fell below the recommended pH value of 6.5-8.5; Omemhi had iron value above the required level of 0.3mg/l and the turbidity of Igbidin and Omemhi were undesirable having exceeded the recommended value of 5NTU.

For the biotic aspect, a total of 70 taxa of algae were identified during the survey, majority being diatoms (55.7%), followed by green algae (27.1%), blue-greens (15.7%) and red alga (1.4%). The diatoms were species of *Eunotia, Frustulia, Pinnularia, Navicula, Fragilaria, Tabellaria and Stauroneis*, while green algae were desmids (*Actinotaenium,Closterium, Cosmarium, Desmidium and Euastrum*), *Oedogonium and Microspora.* The blue-greens were *Spirulina major* and species of *Oscillatoria* and *Lyngbya* and the red alga was *Batrachospermum moniliforme.* The occurrence of diatoms, desmids and the red alga *Batrachospermum* in the streams suggests that they are unpolluted.

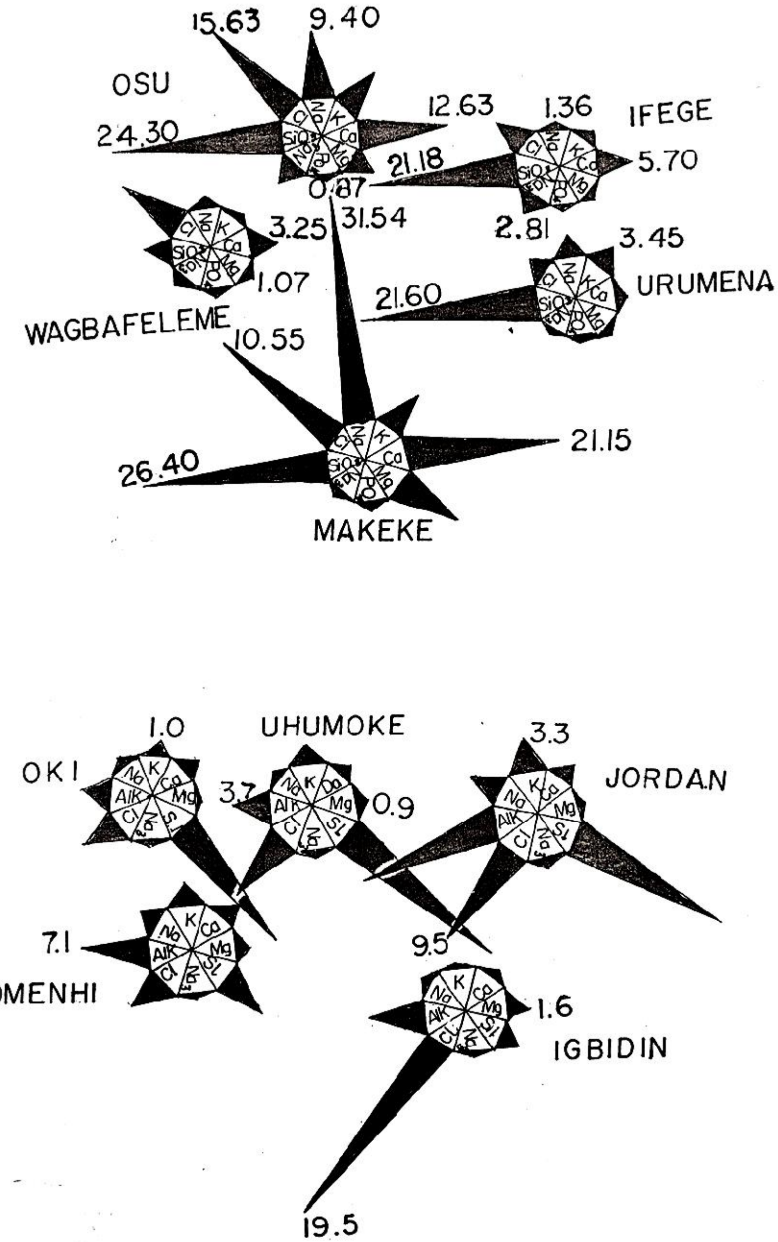


Fig. 1. Summary of cations & anions of some springs in Edo State

3) Ikogosi Springs –Contrasting but closely linked (Warm & Cold springs) [Kadiri, 2000]

Of the four well known thermal springs in Nigeria, Ikogosi is the only one located in southern Nigeria. It is located in Ikogosi-Ekiti, Ekiti State, Western Nigeria. Others namely, Wikki warm spring, Keana warm spring, Awe hot spring are located in northern Nigeria.

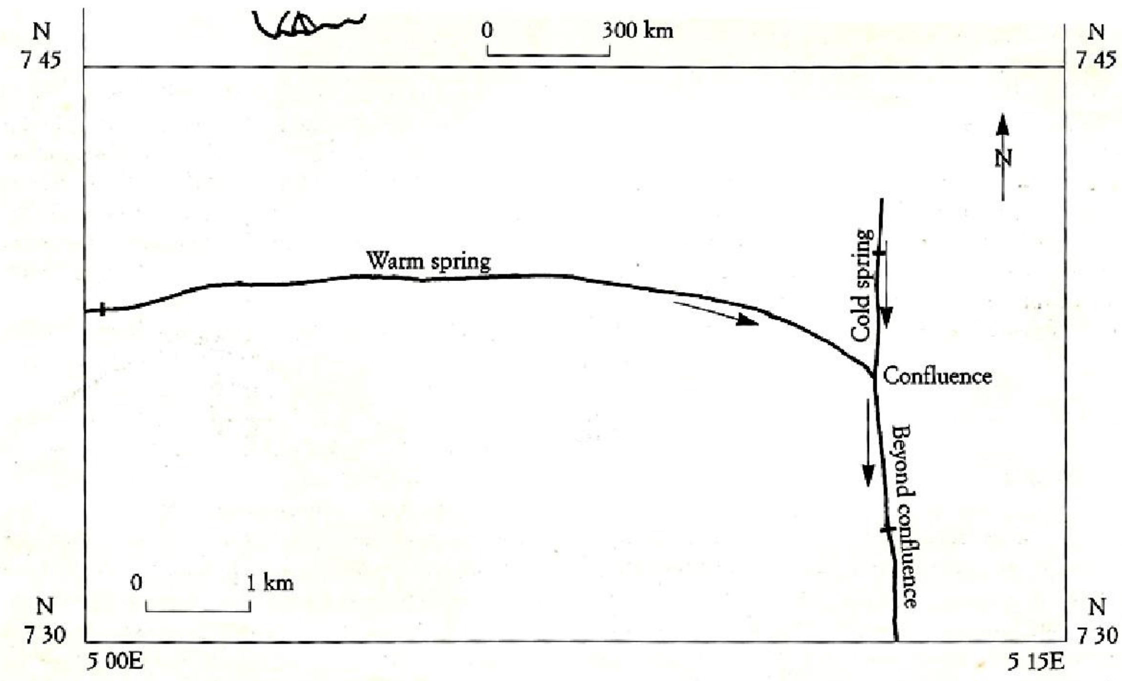


Fig. 2.Diagrammatic sketch of the Ikogosi Springs

Most thermal springs are usually isolated. But Ikogosi (Fig.2.) springs are a micro, unique and interesting ecosystem because they consist of a warm and cold spring, both of which are freshwater ecosystems, separate upstream and joined downstream. The warm spring is fast-flowing, taking a southerly course to merge with the cold spring which is slow-flowing and it is a tributary of Owena River. Four sites were selected for study namely, the warm spring, the cold spring, their confluence and the mixed region downstream.

The temperature of the warm spring was 35°C and cold spring was 24°C. While both springs differed markedly in colour, turbidity, conductivity, solids, total alkalinity, total hardness, Ca, SiO_3 SO_4, Mg, Cl^- and dissolved oxygen (Table 3), they showed similarities in pH, Fe, Na, K, PO_4 and NO_3. The warm spring was dominated by blue-green algae namely *Lyngbya birgei, Synechococcus aequalis* and *Oscillatoria* spp. The blue-green algae are known to be thermophillic. The cold spring was dominated by the green algae *Rhizoclonium hieroglyphicum* and diatom *Navicula* spp; the confluence by *Terpsinoe musica, R. hieroglyphicum* and *Lyngbya birgei* and the mixed downstream region entirely by *R. hieroglyphicum*. The occurrence/dominance of *R. hieroglyphicum* in habitats other than warm spring is ascribable to reduced water flow and/or appropriate substratum which enables attachment with its long stringy strands. In most case, the confluence and downstream region exhibited intermediate characteristics between the warm and cold springs. Colour, suspended solids and turbidity were high at the confluence because of turbulence. Debris is stirred and re-suspended at this location but as the mixed water flows along downstream, it becomes clearer due to settling of the debris. The warm spring meets international standards for drinking water and as such it is recommended for bottling. This must be done at the source where the water issues from the rocks.

Table 3. Water chemistry of Ikogosi springs. (Values are mean seasonal values and are expressed in mg/l, except otherwise stated)

Parameter	**Warm spring**	**Cold spring**	**Confluence**	**Mixed Downstream Region**
Temperature (°C)	35	24	32.88	32.75
Colour (PtCoU)	0.25	15.5	22.25	18
Turbidity (NTU)	1.5	5.5	41.25	18
Total solids	60.1	107.13	141.16	103.75
Suspended solids	13.93	80.88	97.38	62.35
pH	7.12	7.35	7.79	7.81
Total Alkalinity	48.25	5.5	37.00	38.25
Total hardness	49.38	24.5	42.24	40.25
Conductivity (µS/cm)	92.55	52.4	87.6	82.58
Dissolved O_2 Saturation (%)	107.09	80.12	99.95	102.48
Dissolved O_2	7.66	6.8	7.31	7.51

4) Application of algae for Long-term monitoring-English Lakes District, England (Kadiri & Reynolds, 1993).

The English Lake District situated in the North West of England has numerous lakes (Fig.3).

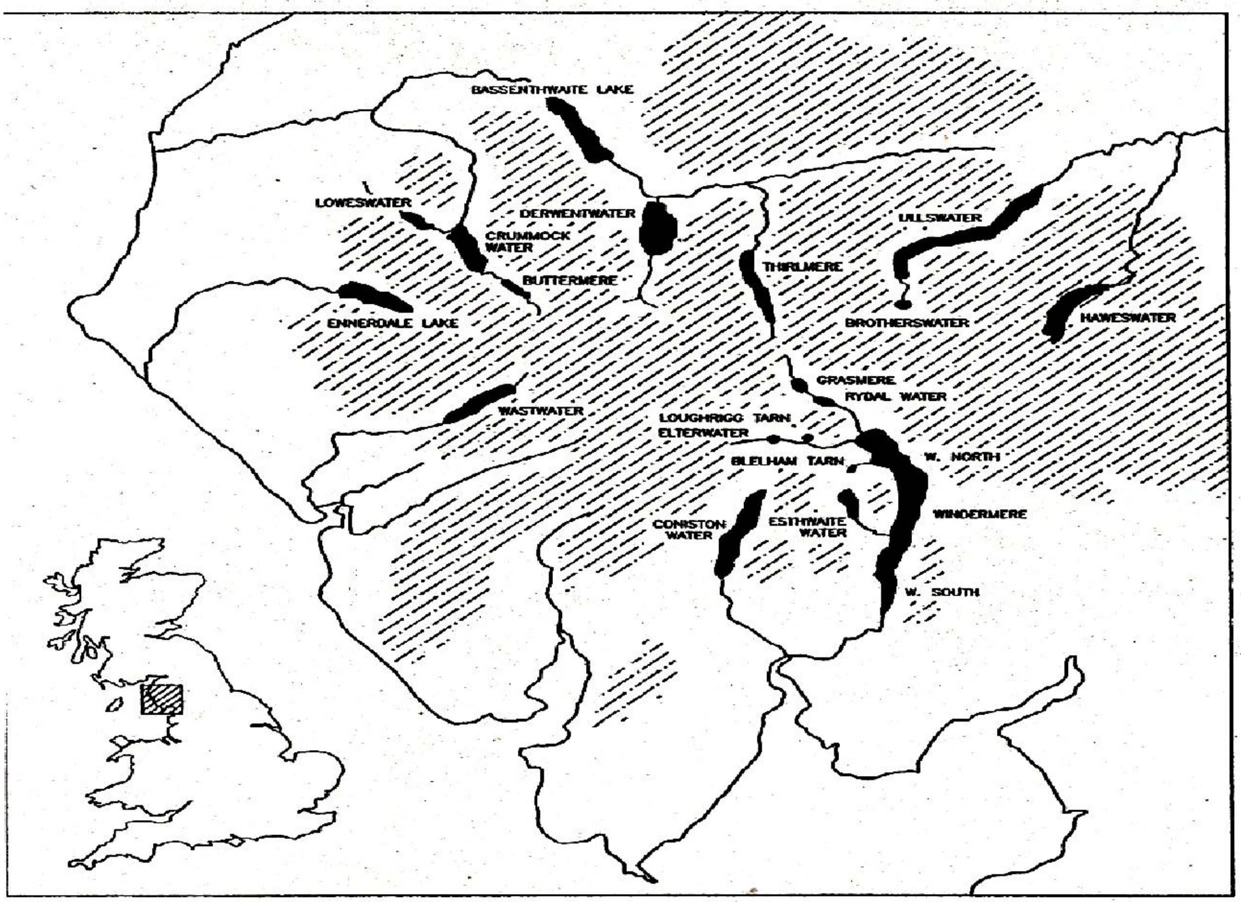


Fig.3. English Lakes

The work describes an approach to the monitoring of well studied lakes employing low logistic effort and maximal sensitivity. It is based on samples collected from spring, early summer and late summer in every fifth or sixth year. The phytoplankton were enumerated and categorized according to size such as < 65µm, >65µm cell/colony dimension and (larger) cyanophytes (Table 4).
Results are summarized as follows:

1Data of four decades are compared

2 Constancy in the *oligotrophic* condition (since 1949) of some of the lakes (Wast Water, Ennerdale, Thirlmere, Crummock Water, & Buttermere

1) Derwent Water, Hawes Water & Coniston Water are *mesotrophic*

2) Windermere North Basin has moved up to *eutrophic* category
3) The approach is recommended for low key monitoring of a series of previously-studied lakes

Some factors responsible for change in position of the lakes after three decades could be predicated on:

a) Nutrient enrichment due to mining and agricultural activities in the catchment area
b) Restoration schemes
c) Size of lakes: small lakes recycle phosphorus and other nutrients more effectively and rapidly than larger ones unless they are shallow and/or very dendritic in shape
d) Effluent input from sewage treatment plant
e) Flushing & retention time of lakes

Table 4. Revised sequence of lakes in English Lakes District. No. in parenthesis are sequence by Gorham *et al* (1974). Values are Approximate dry weight (in µg/l) of overall averaged cells

		1949-1963 (Gorham *et al.*(1974)				1978;1984 (Kadiri & Reynolds, 1993)				
		µ	Large	Cyan	∑	µ	large	Cyan	∑	
1	WastWater (1)	14	9	0	23	7	12	0	19	Oligotrophic larger lakes
2	Ennerdale Water (5)	13	80	0	93	3	74	0	77	,,
3	Thirlmere (2)	14	40	0	55	12	89	0	101	,,
4	CrummockWater (6)	18	80	9	108	9	99	0	108	,,
5	Buttermere (3)	11	59	0	70	13	126	0	139	,,
6	Derwent Water (13)	39	1820	9	1868	20	145	2	167	Meostrophic larger lakes
7	Hawes Water (7)	21	336	9	366	40	637	1	678	,,
8	Coniston Water (9)	58	733	0	791	22	1740	0	1762	,,
9	Brothers Water (4)	-	71	0	~85	43	505	0	548	Well-flushed short retention lakes
10	Rydal Water (11)	-	730	9	~860	25	231	0	256	,,
11	Grasmere (10)	-	860	9	~910	118	1789	0	1907	,,
12	Bassenthwaite Lake(19)	100	4109	19	4228	75	2242	7	2324	,,
13	Windermere North Basin (12)	56	1300	19	**1375**	41	2076	246	**2363**	**Eutrophied larger lakes**
14	Ullswater (18)	34	3702	66	**3802**	14	3388	11	**3413**	,,
15	Windermere South Basin (15)	104	2461	230	**2795**	52	3068	490	**3610**	,,
16	Esthwaite Water(20)	47	5695	1100	**6842**	77	1820	141	**2038**	,,
17	Loweswater (14)	48	1842	260	**2150**	31	4050	49	**4130**	,,
18	Loughrigg Tarn (17)	-	3576	66	**~3700**	92	1026	992	**2110**	**Enriched smaller lakes**
19	Blelharm Tarn (16)	105	3419	76	**3600**	44	10555	654	**11253**	,,
20	Elterwater (8)	6	440	47	**493**	310	12769	2	**13081**	Enriched shallow lake

~ = values nominated by Gorham *et al.* (1974)

5) Algal Composition/Community structure & Pollution Studies

Pristine water bodies (Pre-pollution studies)

a) **River Okhuahe**, on Agbor Road, Benin City (Kadiri & Omosuzi, 2002). This study entailed both abiotic and biotic environments.

i) Abiotic Environment

The results of the chemical parameters are shown in Table 5

Table 5. Chemical parameters of River Okhuahe

pH	5.35 ± 0.16
Conductivity (µS/cm)	11.00 ± 0.32
Total Alkalinity (mg/l $CaCO_3$)	4.38 ± 0.28
Total hardness (mg/l $CaCO_3$)	3.4 ± 0.15
Ca (mg/l)	2.0 ± 0.04
Mg (mg/l)	1.5 ± 0.15
Na (mg/l)	1.72 ± 0.12
K (mg/l)	0.74 ± 0.10
Cl^- (mg/l)	1.66 ± 0.1
Si (mg/l)	3.14 ± 0.16
NO_3 (mg/l)	0.029± 0.005
PO_4 (mg/l)	0.27 ± 0.056

These represent baseline data for the river against which future impact will be compared.

ii) Biotic component (phytoplankton flora)

Sixty -one phytoplankton taxa categorized into Chlorophyta or green algae (46 taxa), Bacillariophyta or diatoms (12 taxa) and Cyanophyta or blue-green algae (3 taxa). Majority of the green algae were desmids represented mainly by the genera *Closterium* and *Cosmarium*, and fairly by *Euastrum, Staurodesmus* and *Hyalotheca dissiliens.* The preponderance of desmids is an indication that the water largely unpolluted. The diatoms sparingly represented by *Tabellaria, Navicula, Surrirella* etc while the blue-green were filamentous forms such as *Scytonema, Oscillatoria* and *Anabaena.*

b) **Ikpoba Reservoir**

The Ikpoba Reservoir was dammed from the Ikpoba River in 1982. Studies were done from 1983 to 1984 (Kadiri, 2000) (Table 6). The results revealed that the seasonal pattern exhibited by the environmental variables was segregated into three:

a) Wet season maximum as a consequence of increased precipitation with concomitant increase in surface run-off (conductivity, phosphate, pH, alkalinity, total iron, sulphate, nitrate & silicate)
b) Dry season maximum arising from evaporation of reservoir water, low precipitation coupled with a reduction in surface run-off (chloride, sodium, potassium, calcium & dissolved oxygen)
c) Parameters with no discernible pattern or effect of season (magnesium & total hardness)

Table 6. Chemical parameters of Ikpoba Reservoir (concentrations are in mg/l except otherwise stated)

Parameters	**Mean ± SE**		**Range**	
	1983	1984	1983	1984
pH	5.07 ± 0.04	5.85 ± 0.06	5.3-6.0	4.9-6.8
Total alkalinity (meq/l)	0.6 ± 0.005	0.45 ± 0.26	0.22-0.68	0.22-0.65
Conductivity (µS/cm)	15.81 ± 0.03	16.95 ± 0.03	14.1-20.7	14.0-19.3
Total hardness (mg $CaCO_3$/l)	6.78 ± 0.01	6.77 ± 0.01	5.9-7.6	5.7-7.7
Na	3.64 ± 0.09	2.34 ± 0.1	2.0-5.3	1.7-3.5
K	0.82 ±0.004	1.67 ± 0.007	0.5-1.2	1.3-2.4
Mg	0.25 ± 0.03	0.28 ± 0.03	0.07-0.52	0.15-0.53
Ca	9.4 ± 0.04	11.09 ± 0.05	7.2-10.8	5.5-14.8
Total Fe (µg/l)	45.17 ± 1.31	20.73 ± 0.94	1.0-98.6	6.3-80.5
Silicate	12.92 ± 0.14	13.74 ± 0.10	10.7-23.6	10.2-20.5
Sulphate (µg/l)	26.05 ± 0.33	18.76 ± 0.28	4.1-68.8	4.7-62.2
Chloride	1.51 ± 0.002	1.35 ± 0.002	1.0-3.1	0.9-2.2
Phosphate	0.63 ± 0.04	0.46 ± 0.02	0.56-0.72	0.42-0.52
Nitrate-nitrogen (µg/l)	13.33 ± 0.07	11.13 ± 0.07	10.5-17.2	2.9-14.6
Dissolved oxygen	4.28 ± 0.05	3.9 ± 0.04	3.25-6.46	2.19-5.82
Dissolved oxygen saturation (%)	56.1 ± 0.06	46.52 ± 0.03	36.9-70.4	26.0-59.6

The reservoir generally had low levels of nutrients. The water chemistry of the reservoir is explained on the basis of the underground lithology and adjoining soil profile composition. Thus the elemental composition of the reservoir is a reflection of the nutrient-poor sandy soil interspersed with patches of lateritic sandy clay in the drainage area.

The significance of the pre-pollution studies above are:

a Provides a basis to measure future environmental impacts or pollution of the water course
b. Data will be useful in restoration programmes
c. Development of proper management (fisheries, water quality etc)
d. Planning conservation strategies

Eutrophication of Ikpoba Reservoir

Eutrophication is a process of nutrient enrichment in water bodies. The Ikpoba Reservoir was constructed in 1982.

A comparison of data from the Ikpoba Reservoir after 25 years (post) of impoundment reveals a 271-329 % (60- 76.8 /14.0-20.7) increase in nutrient load or eutrophication. Eutrophication may be anthropogenic or external input otherwise known as cultural eutrophication or natural eutrophication (natural aging of the reservoir). The nutrient enrichment in Ikpoba reservoir may have resulted from both natural aging and anthropogenic input. Excessive nutrient load can cause algal bloom with consequences for water supplies. These could include imparting taste, colour and ordour, clogging of water treatment facility filter etc.

6) River Niger (Kadiri, 1999c)

River Niger is the third longest river in West Africa with a length of 4200 km and water she area of about 1,250,000 km^2 (John, 1986). It flows through many countries. It takes its source in the north from Guinea highland, flows north-eastward through Mali, then southwards through Niger and finally into Nigeria where it finally enters the Atlantic Ocean via a delta popularly called **Niger Delta.**

The lower River Niger (Nigeria) (Fig. 4) was investigated for physical and chemical characteristics and phytoplankton and found to be low in total ion concentration, conductivity (mean =56.4µS/cm) as nitrate (0.50mg/l), phosphate (0.036mg/l) (Kadiri, 1999c). Floristically, the phytoplankton flora was very diverse with 117 taxa classified into Bacillariophyta, Xanthophyta, Chlorophyta, Chrysophyta, Cyanophyta, Dinophyta and Euglenophyta. Chlorophyta was preponderant with desmids comprising 24% of the total flora. The profusion of desmids is an attestation of the low nutrient level of the river. Desmids are characteristic of freshwater environments with poor ionic composition (Kadiri 1988, 1993a, 1993b, 1996). The low nutrient status of the river is further corroborated by low density of euglenoids and blue-green algae which ordinarily are typical of nutrient-rich or eutrophic water bodies (Conforti, 1991).

The taxa that were widely distributed along the river, among the diatoms, were *Aulacoseira granulata* var. *granulata, A. granulata* var. *curvata,* A. *granulata* var. *angustissima,* A. *granulata* var. *angustissima f. spiralis, Synedra ulna* var. *ulna* and *Surirella ovalis.* Of the green algae were *Chlorella vulgaris, Eudorina elegans, Pediastrum gracillimum, Scenedesmus quadricauda, Staurastrum lezae* and among the blue-green algae were *Merismopedia elegans* and *Oscillatoria* spp and *Phacus longicauda* as the most widely distributed euglenoid. Quantitatively, the phytoplankton population was dominated by *A. granulata* especially *A.*

granulata var. *angustissima*.

Spectacularly, station 5 along the river Niger was quite a unique ecozone. It represents a confluence of two water bodies-the River Niger itself and an adjoining creek. The data obtained at this station were outstanding between the two ecosystems. Most physical and chemical parameters as well as all the ecological indices (phytoplankton density, diversity, evenness and richness) were highest at this station. The fundamental reason for highest phytoplankton parameters (diversity and cell numbers) obtained is that the station represents a more heterogeneous system with varying conditions and consequently provides opportunities permitting the development of a wide array of phytoplankton flora.

The imports of this study are:

a) It provided the first report of phytoplankton in River Niger within Nigeria
b) It provided phytoplankton information of the lower reaches of R. Niger which was hitherto scarce (John, 1986)
c) It addressed total biomass and quantitative distribution of component algal species which are generally very few in Africa (Talling, 1986)

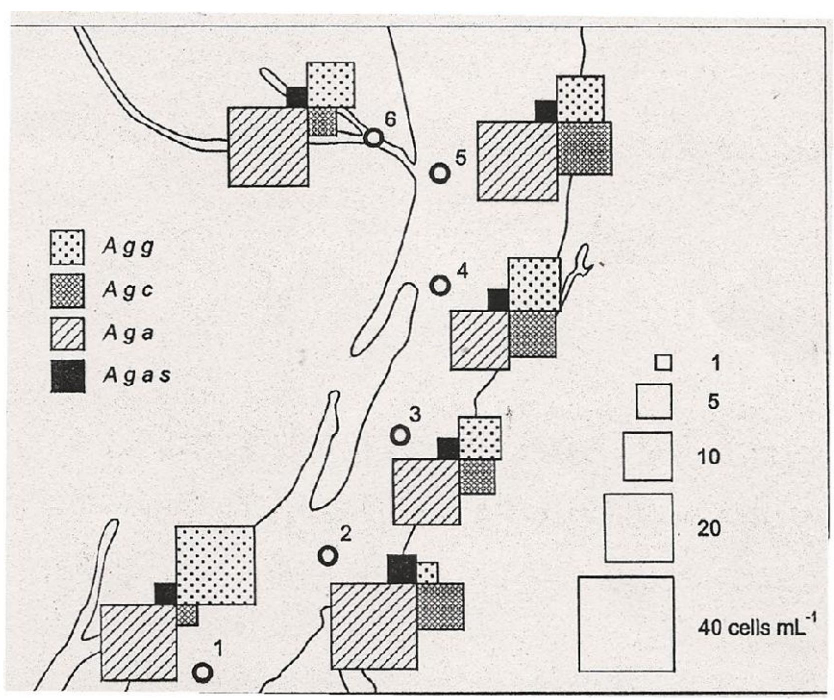


Fig. 4. Spatial variation in varieties and forms of dominant diatoms along River Niger

(Agg = *Aulacoseira granulata* var. *granulata;* Agc = *Aulacoseira granulata* var. *curvata;* Aga = *Aulacoseira granulata* var. *angustissima;* Agas= *Aulacoseira granulata* var. *angustissima f spiralis*)

7) Niger Delta Studies

The Niger Delta area is very important for several reasons:

a) It is one of the largest deltas in the world, covering an area of 70,000 km^2
b) It comprises four ecological zones-coastal barrier islands, mangrove forests, freshwater swamps, and lowland rainforest.
c) It harbours the world's third largest and Africa's largest contiguous mangrove Swamp Forest
d) The freshwater swamps of the Niger Delta (area 11,700 Km^2) is the most extensive in West and Central Africa (Moffat & Linden, 1995)
e) It is endowed with immense natural resources, particularly crude oil which is the mainstay of Nigerian economy

Influence of Saline environments on algae (Kadiri, 2002).

Phytoplankton distribution along salinity gradient was studied in the eastern Niger delta region. The phytoplankton were separated into three distinct categories-those tolerant of low narrow salinity range (stenohaline), those adapted to high but also narrow salinity range and those tolerant of wide salinity range (euryhaline).

Low Stenohaline species
Oscillatoria princeps
Merismopedia elegans

Euryhaline Species
Bacillaria paradoxa
Chaetoceros lorenzianus
Coscinodiscus spp
Ditylum brightwelli
Odontella longicruris
O. sinensis
Pleurosigma angulatum

Shuelta annulata
Ceratium fusus
C. furca
Actinoptichus splendens
Amphiprora alata
Aulacoseira numuloides
Cyclotella meneghiniana
Gyrosigma balticum
Lauderia borealis
Terpsinoe musica
Pleurosigma australe
P. delicatulum

High Stenohaline Species
Triceratium favus
Nitzschia accicularis
N. obtusa
Thalassiosira nitzschiodes
Pleurosigma decoratum

Bacteriastrum hyalinum
Dinophysis caudata
Peridinium gatuense
Ditylum sol etc etc

The species tolerant of wide salinity range were more than those with low salinity ranges-whether low or high. This can be aptly explained on the basis that at wide salinity range, many different taxa are afforded the opportunity of exploiting available niches in the environment. On the contrary, only a few species are able to tolerate extreme salinity-low or high. The ecological implication of this study is that varying salinities can trigger off bloom formation of certain algae, particularly dinoflagellates and cyanobacteria (Pearl, 1988). Whereas oligohaline regions i.e. areas of salinities 0-5‰ are conducive sites for cyanophyta bloom formation, salinities greater than 5‰ are favourable for formation of bloom by dinoflagellates (Pearl 1988, Opute 1990).

Phytoplankton Survey In the Western Niger Delta

A comprehensive phytoplankton survey was carried out in the Western Niger Delta areas (Kadiri, 2006a) covering Escravos river, Chanomi creek, Warri River, Forcados river and Nana creek. The taxonomic examination reveals a floristic diversity of 72 phytoplankton taxa belonging to six divisions of Bacillariophyta, Chlorophyta, Cyanophyta, Dinophyta, Euglenophyta and Rhodophyta, the majority being diatoms (Bacillariophyta). There was spatial variation in phytoplankton biomass (density), distribution and community structure indices. Generally, there was a transition or shift in dominant taxa between the stations among *Fragillaria construens, Coscinodiscus* spp. *Surirella ovalis, Aulacoseira granulata* var. *curvata* and *Actinoptichus splendens.* The most widely distributed taxa were *Coscinodiscus* spp. There was a great deal of variability in ecological indices (diversity, evenness and dominance) during this study. Generally, low species diversity and evenness are attributable to high density of certain dominant species. Such a decrease in diversity and its concomitant increase in abundance is a common community response to environmental disturbance. While diversity means variability, evenness refers to the distribution of individuals within species designations.

Eastern Niger Delta

A survey was carried out in a large expense of water between Bartholomeo River and Sego creek (Kadiri, 2006b) in the eastern Niger Delta. It was found that the bulk of the phytoplankton (39 out of 49) were diatoms. Others were two taxa of Chlorophyta (green algae), four Cyanophyta (blue-green algae), three Dinophyta (dinoflagellates) and one Euglenophyta euglenoid). The water mass had neutral pH and extremely high conductivities (3.2 – 17.0 mS/cm. The phytoplankton population was dominated by *Coscinodiscus*. The preponderance of centric diatoms is reminiscent of brackish/marine environments.

Other Western Niger Delta Survey

Warri River at Opete

Egborge & Kadiri (2001) in a pollution study of Warri River at Opete, found only thirteen taxa, comprising Bacillariophyta or diatoms (7), Chlorophyta or green algae(3), Cyanophyta or blue-green algae (3). The diatoms comprised species of *Aulacoseira, Pinnularia and Surirella* while the green algae were Volvocales (*Eudorina, Volvox)* and *Spirogyra.* The study revealed that the species *Aulacoseira granulata* var. *curvata* was preponderant in the less polluted up- and downstream stations while *A. granulata* var. *angustissima* f. *spiralis* was dominant in the more polluted waters at Opete.

Ethiope River

Kadiri (2007b) studied the seasonal influence on the dynamics of phytoplankton composition, density and diversity of River Ethiope. The river was oligotrophic i.e low in nutrients and showed distinct seasonal differences. Diatoms, green algae and blue-green algae were found in the dry season, while euglenoids occurred in addition to these in the rainy season. Similarly, centric diatoms were more common in the rainy season than in the dry season. Quantitatively, the dominant taxa during the rainy season were *Aulacoseira* species whereas, in the dry season, phytoplankton flora was dominated by the baculiform desmid- *Desmidium aptogonium* var. *tetragonium* and a filamentous pennate diatom *Fragillaria construens.* The ecological or community structure indices of the rivers exhibited spatial differences.

8) My Atlantic Ocean Phycological Voyage

Hardly has any phycological studies been done in the Atlantic Ocean per se in Nigeria probably because of logistics problems (funding). What are commonly available are studies on associated lagoons. This study (Kadiri, 2001) was undertaken in North Chioma area and the phytoplankton collection comprised only 53 taxa in three divisions-Bacillariophyta (diatoms), Dinophyta (dinoflagellates) and Cyanophyta (blue-greens). The bulk was made up of diatoms (52%) comprising 21 centric forms out of the total 28 taxa and were characteristically marine flora some of which were diatoms, *Ditylum, Odontella, Thalassiothrix,* dinoflagellates, *Peridinium*, *Ceratium, Peridinium, Prorocentron* and *Protoperidinium.* Centric diatoms are more common than pennate forms in marine environments.

9) Algal Biomass

- Field studies-seasonal changes in Biomass

Africa is naturally endowed with tropical water bodies inclusive of the world's longest river (River Nile, 6670 km length), oldest, largest lake (Lake Victoria, 69000 km^2 area) and deepest lakes (Lake Tanganyika, 1470m depth; Lake Malawi, 704 m depth). African lakes generally are of great diversity in origin, physiography, physical and chemical characteristics. Despite the wealth of lakes in the African continent, and the fact that seasonal changes in phytoplankton began since 1899, information on the subject matter became available only much later (Talling, 1986).

This study is on seasonal variation of phytoplankton biomass in a man-made lake (Ikpoba Reservoir) [Kadiri, 1993c]. The range was 4.20 – 35.20 mg m^{-3} , with a mean of 11.00 ±) 0.24 mg m^{-3} .The typical seasonal pattern was a major peak in biomass usually occurring in the dry season-February and a minor peak in late raining season between August and November (Fig. 5). The seasonal changes were related to environmental factors and were found to be positively correlated with light intensity, dissolved oxygen and colour but negatively correlated with turbidity. The negative correlation with turbidity implies that the turbidity of the reservoir was of abiogenic rather than biogenic origin.

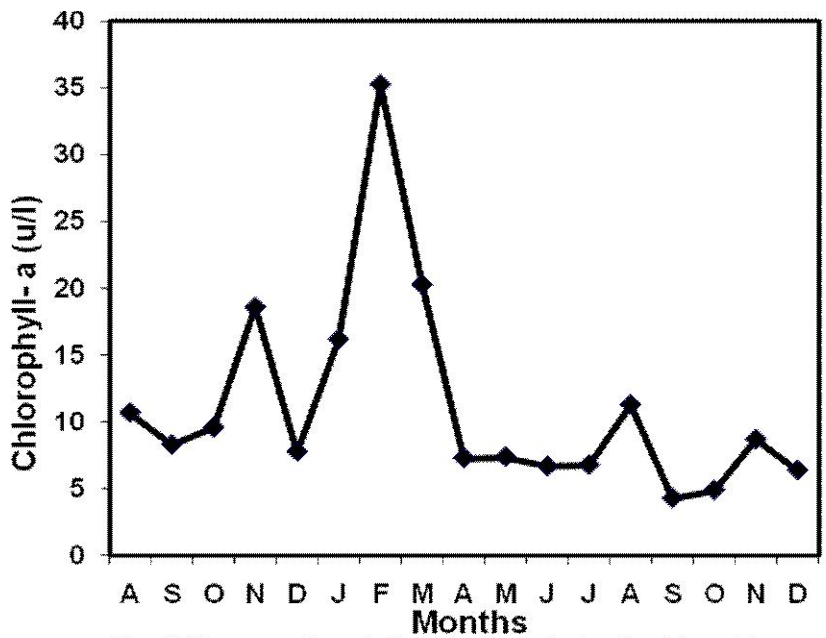


Fig. 5.Seasonal variation in the phytoplankton biomass of the Ikpoba Reservoir

Generally, phytoplankton seasonality is determined by hydrographic regulation of water column characteristics and hydrological regulation by water input-

output influences (Talling, 1986). Hydrographic factors were not considered important in the reservoir because it is shallow, unsheltered and therefore vulnerable to regular mixing by winds and hence unstable. Hydrological regulation was therefore considered more influential. Low biomass values could be attributed to outflow of algae coupled with low nutrient supply (conductivity = 14.0-20.7 µS/cm). Outflow of algae is caused by continuous overspill during the dry season (draw down) and rainy season as well as flood in the rainy season. Seasonal fluctuation in the abundance of phytoplankton is also ascribable to physical and chemical characteristics of the water, which are themselves dependent on rainfall, grazing, sedimentation and cellular senescence.
It is concluded that:

a) such facilities as Ikpoba Reservoir which are utilities for water abstraction that planktonic algal biomass (chlorophyll *a*) should be regularly monitored as an index of raw water quality. Low biomass implies better quality and vice-versa. The information on the biomass level is important to the water treatment engineer as to what algae are present and in what quantity, hence appropriate treatment. Different algae cause different water treatment problems eg. Some are filter clogging, taste, ordour and colour-imparting.
b) For harvesting of algal biomass from such natural environments such as Ikpoba Reservoir, dry season will yield maximum harvest.

- **Laboratory studies- production (cultivation) of algal biomass**

Why is algal biomass production important?

Advantages of producing biomass from algae

According to Benemann (1997), microalgae are endowed with special features that make them more productive than higher plants. These include:

- the opportunity of large scale continuous culturing
- their ability to control cell composition without reducing productivities
- their ability of providing optimum nutrient levels at all times
- their ability of adjusting harvest rates to maintain optimum culture concentration level at all times

Many tropical countries due to the favorable climatic conditions are suitable for mass production of algal biomass at low cost, which subsequently are useful in carbondioxide sequestration (and consequently global warming amelioration) and biofuel projects.

Experimentally, research done on production of algal biomass includes that of Kadiri & Emmanuel (2003). It involved the examination and growth of algae in organic and inorganic media employing both natural (aerial) and artificial inoculation. The organic medium was biofertilizer (cow dung and poultry droppings), while the inorganic fertilizer was NPK triple super phosphate (15:17:17). In both experiments, poultry droppings elicited optimum growth response.

The results are summarized as follows:

a) Organic fertilizer (manure) resulted in higher growth and biomass compared to inorganic (NPK) fertilizer
b) Of the organic fertilizer, poultry droppings was the best substrate
c) Combination of organic fertilizer with inorganic fertilizer (’spiking’) was of no consequence
d) It is suggested that the surface: volume ratio of the algae probably played a key role in determining the maximum biomass production.
e) *Chlorella* which is a small unicellular green alga was dominant in the aerially inoculated batches.

The study has:

i) environmental consideration because it results in the utilization of wastes which would have littered the environment
ii) agricultural (aquacultural) implications because they are used as food for commercially important organisms such as fish, clams, mussels, oysters and scallops and thus can lead to increased fish yield etc
iii) energy consideration because the algae so produced can be used in biofuel production

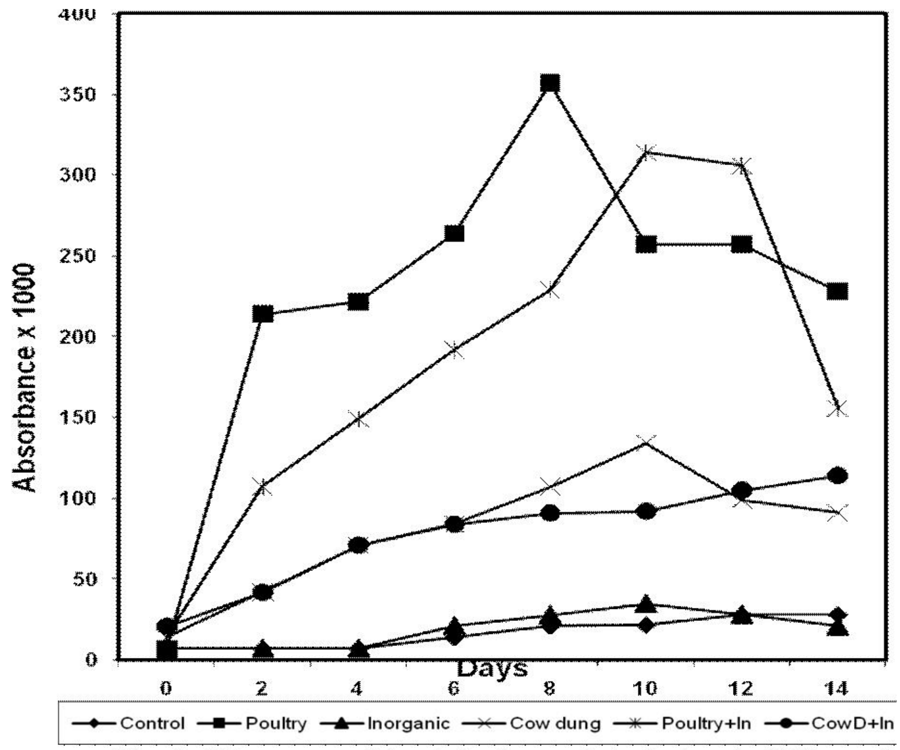


Fig. 6. Biomass of Aerially inoculated alga in Different substrates

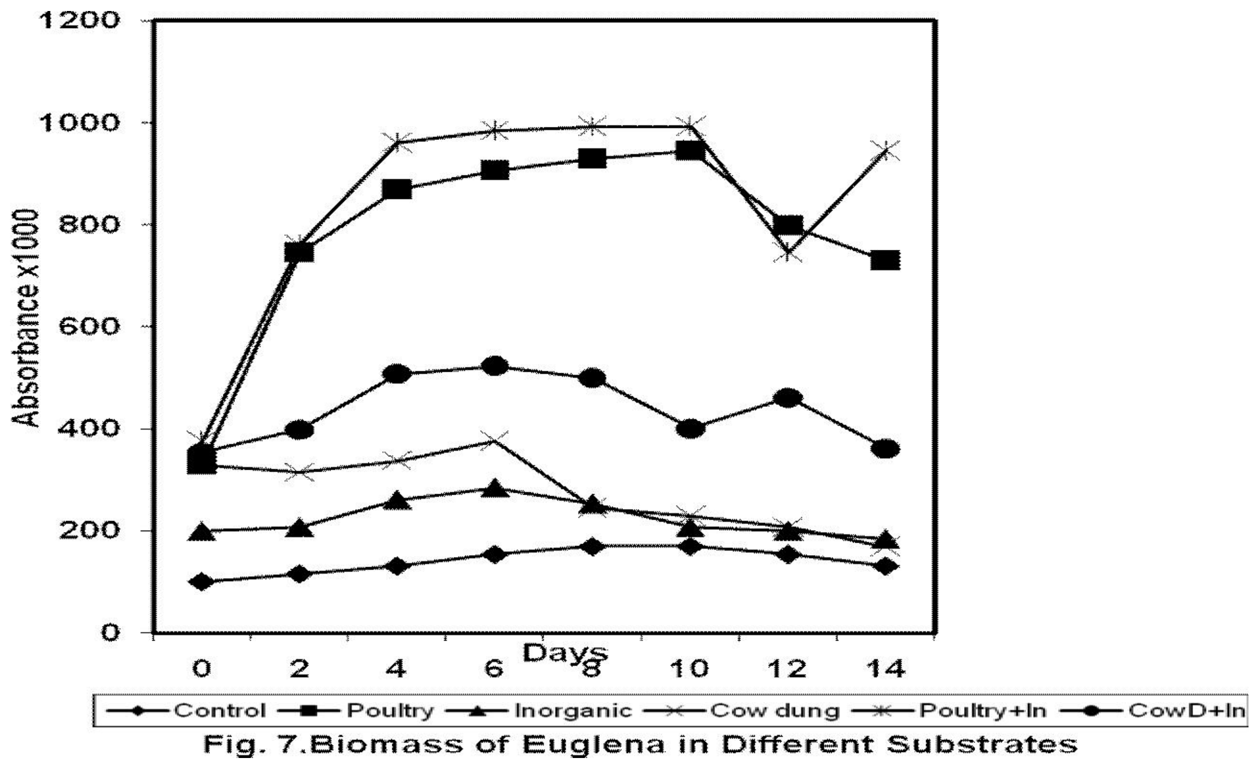


Fig. 7.Biomass of Euglena in Different Substrates

EXAMPLES OF ALGAE WE HAVE SUCCESSFULLY CULTIVATED

Other algae we have successfully grown in the laboratory to date include:

Ankistrodesmus falcatus	*Sphaerocystis schroeteri*
Closterium acerosum	*Phacus curvicauda*
Chlorella vulgaris	*Eudorina elegans*
Scenedemus acutus	*Selenastrum capricornutum*
Scenedesmus quadricauda	*Euglena acus*
Oedogonium grande	*Phacus tortus*
Oscillatoria bornettia	*Microcystis aeruginosa*
Spirulina platensis	*Coelastrum microsporum*

10) Harmful Algal Survey

This is reported in Kadiri (1999d, 2002, 2009) indicated in earlier pages

11) APPLIED PHYCOLOGY

Bioassessment (Bioassay)

Bioassessment or biological assessment (bioassay) is defined as the measurement of the effects of a substance on living organisms.

Biological communities reflects the overall ecological integrity of the aquatic ecosystems

Algal assay is one of the various methods of investigating pollution or aquatic environmental deterioration or water quality alteration. It is often used as to determine the ability of the water system (natural or waste water) to support, accelerate or inhibit algal growth. It is applied to assess the sensitivity of a recovery water bodies to nutrient changes, effects of secondary and tertiary waste water effluents; nutrient limitations in water bodies of various geographical regions. Such alteration in water quality can be simulated in laboratory using algal cultures to measure their growth response to such changes (de Kuhn *et al.* 2006; Birk & Hering, 2009). Different names such as Algal Assay Procedure (AAP), Algal Assay procedure Bottle Test have been used to describe the procedure.

Algae are very useful in bioassay studies because they represent the first link in the food chain of any aquatic ecosystem consequently any effect on them is translated along the food chain to higher trophic levels. Their advantages include:

a) Their sensitivity to pollutants

b) They are photosynthetic and thus primary producers and are directly affected by the physical and chemical environment
c) Rapid reproduction rates and short life-cycle
d) Inexpensive method

Studies were conducted on the growth response of algae to brewery effluent (Kadiri & Azomani 1993, 1997, 1998, 1999).

Industrial Effluents

Guinness -Nutrient-influenced growth response (Kadiri & Azomani, 1993)
Nutrients are added to water bodies to determine nutrient limitation or possible enrichment of the water bodies.

i) Natural (indigenous) algal population:

This research was done by adding nutrients to the natural algal population. Various combinations in µg/l of $0^P/0^N$, $100^P/0^N$, $100^P/50^N$, $100^P/200^N$, $25^P/50^N$, $50^P/50^N$ & $0^P/200^N$ were used. The findings are as follows:

- Growth was optimum at $100^P/200^N$ at points before and after the point of discharge of effluents and $100^P/50^N$ at point of discharge
- The overall algal response to nutrient addition is dependent on the background level of the limiting nutrient as well as the nutrients combination
- The algae supported by the nutrient combinations were green algae and diatoms.

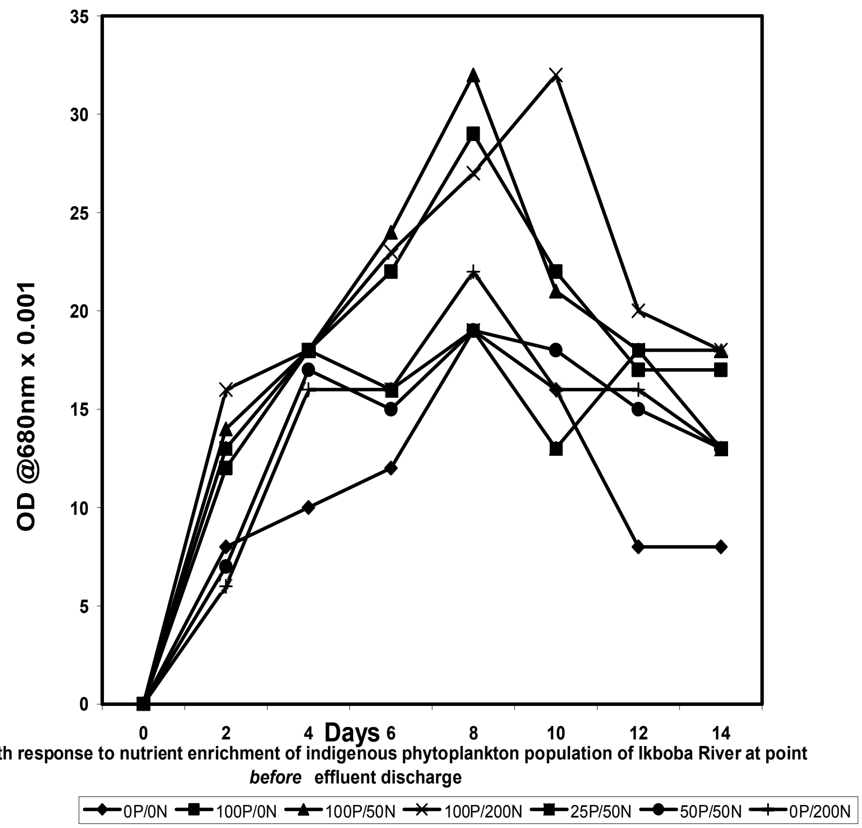


Fig. 8.Growth response to nutrient enrichment of indigenous phytoplankton population of Ikboba River at point *before* effluent discharge

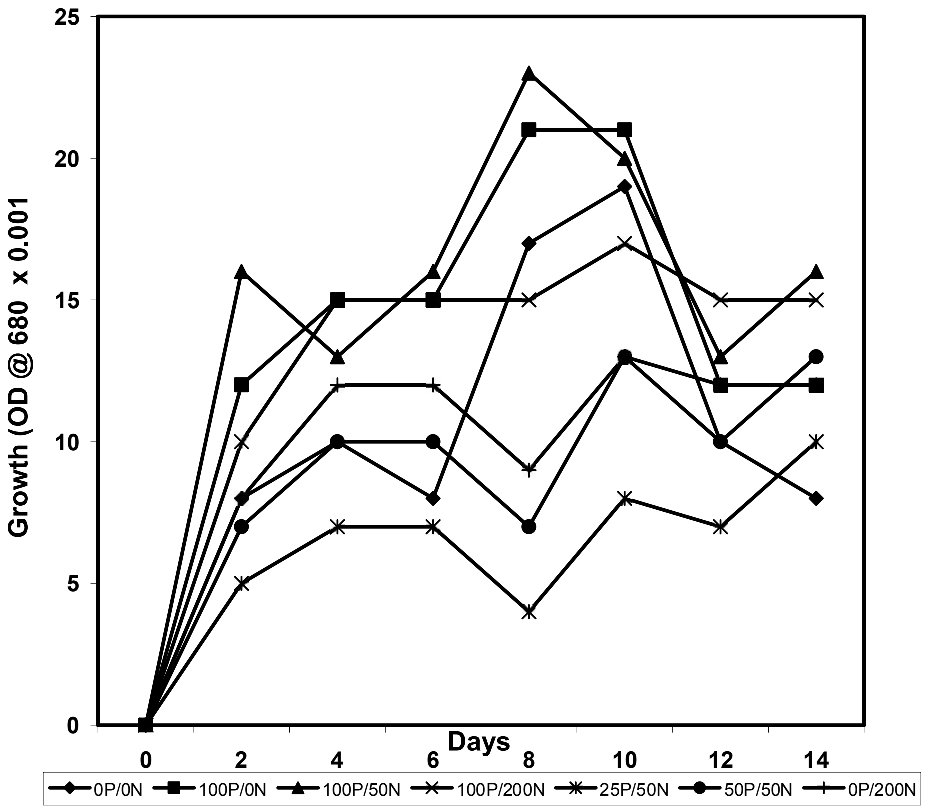


Fig. 9.Growth response to nutrient enrichment of indigenous phytoplankton population of Ikboba River at point *of* effluent discharge

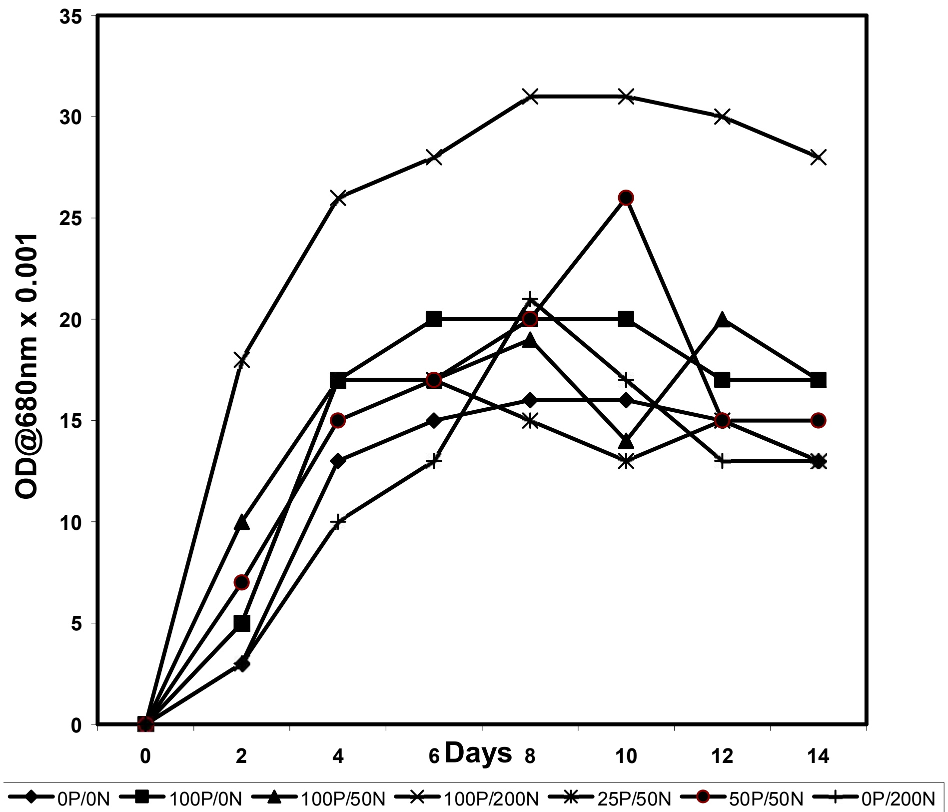


Fig. 10. Growth response to nutrient enrichment of indigenous phytoplankton population of Ikboba River at point *After* effluent discharge

ii) Using a test alga: (Kadiri & Azomani 1999)

Nutrient-influenced response to Guinness brewery effluent discharge into the Ikpoba River was investigated using a desmid (*Mesotaenium caldararium*) obtained from the Culture Collection Centre of the Institute of Freshwater Ecology, UK. Nutrient spiking was done with 50g/l NO_3 + 100g/l PO_4.

The result is summarized below:

1) Growth response is in the order AD+N>AD>BD+N>BD
2) Growth was least in Effluent/Effluent+N

- Growth stimulation in:
  - -BD+N =35.5%
  - -AD+N =55.4%
  - -AD =40.4%
  - -PD+N =4.8%
- Growth inhibition in:
  - -BD =36.1%
  - -PD =6.6%
  - -EF/EF +N=35.5

The scientific contribution of this study is that it finds application in lake restoration programmes as well as in biological effluent treatment technology. It is suggested that the 'point after the discharge' of effluent be targeted for this purpose.

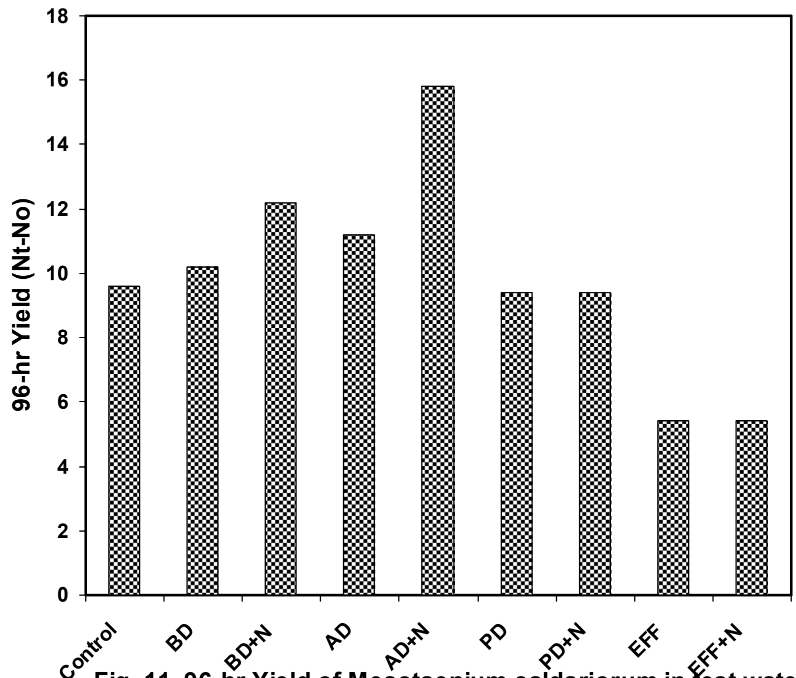


Fig. 11. 96-hr Yield of Mesotaenium caldariorum in test waters

Other Industrial effluents studied:
Paint Effluent, Rubber Effluent, Coca cola Effluent, Refinery Effluent and Composite Effluent (Schlumberger + Halliburton + Nigerian Bottling company effluents)

Bioremediation studies (Phycoremediation)

Bioremediation can be defined as application of biological agents in the removal or neutralization of contaminants. It is a bio-restoration technology involving the use of living organisms and it is relatively new in Africa (Ezemonye & Kadiri, 2000). The application of bioremediation in the restoration of aquatic environments is predicated on the ability of uptake and accumulation of pollutants by organisms. This is dependent on the absence of environmental conditions inhibitory to the growth and reproduction of the bioremediating organisms, as well as accessibility of the contaminants to the organisms.
Phycoremediation refers to the use of algae in treating waste water and

industrial effluents. Micro algae are superior organisms for remediation because a wide range of toxic and other wastes can be treated with these algae and they are non pathogenic. The risk of accidental release into the atmosphere causing health safety and environmental problems is avoided when algae are employed for remediation. Algae utilize the wastes as nutritional sources and enzymatically degrade the pollutants. Xenobiotics and heavy metals are known to be detoxified/ transformed/or volatilized by algal metabolism (Sivasubramanian 2009).

Heavy Metals bioremediation by algae (Abirire & Kadiri, 2010)
The algae studied could be separated into two groups on the basis of uptake rate.

These were:

1) Algae with long continuous uptake of heavy metals at the beginning of the experiment and short term uptake towards the end of the experiment e.g *Phacus curvicauda* (Zn, Fe and Al), *Chlorella vulgaris* (Fe and Cd), *Euglena acus* (Zn, Fe and Cu) and *Oscillatoria bornettia* (Zn and Al)
2) Algae with long continuous uptake throughout the experiment e.g *Phacus curvicauda* (Fe, Cu and Cd). *Chlorella vulgaris* (Zn, Cu and Al), *Euglena acus (*Cd) and *Oscillatoria bornettia* (Fe, Cu and Cd). A “mean metal concentration factor” was used to quantify the absorption capacity of the algae (Table 7). Of all the metals studied, concentration factor was highest for Al and least for Cu. Apart from Al in which *Phacus curvicauda* and *Euglena acus* had the same and highest absorption capacity of 0.566, *Oscillatoria bornettia* had the highest absorption for all other metals: Zn (0.306), Fe (0.302), Cu (0.092) and Cd (0.276).

Table 7. Mean Concentration Factor of test algae for some heavy metals

Metal	*Chlorella vulgaris*	*Phacus curvicauda*	*Euglena acus*	*Oscillatoria bornettia*
Zn	0.225	0.175	0.141	**0.306**
Fe	0.237	0.266	0.188	**0.302**
Cu	0.062	0.089	0.029	**0.092**
Cd	0.151	0.267	0.217	**0.276**
Al	0.383	**0.566**	**0.566**	0.439

The implication of this study is that algae can be employed in bioremediation of heavy metal pollution. According to Ezemonye & Kadiri (2000), such bioremediation in aquatic environments can be applied in pollution control process such as

(a) in situ sediment treatment
(b) waste water treatment augmentation

Crude Oil /petroleum hydrocarbon Studies

Studies with the Water Soluble Fraction (WSF) of Bonny Light crude oil using micro algae (Kadiri & Emmanuel, 2006).
The algae grown in 10%, 25%, 50%, 75% and 100% concentrations of water soluble fraction and growth response shows that there was stimulation of growth at lower (10%, 25%, 50%) and suppression at higher concentrations (75% and 100%). Maximum growth occurred in 50% concentration of WSF of crude oil in all algae.

Aromatic Hydrocarbon WSF Studies

Similarly, test algae were grown in 0%, 50%, 100% and 200% concentrations of toluene and Xylene for 14 days. Growth response revealed that there was stimulation at 50% and suppression at higher concentrations (100% and 200%). Maximum growth was also recorded in 50% concentration of hydrocarbon. The comparative toxicities of the two aromatic hydrocarbons show that xylene was more inhibitory to algae than toluene (Fig. 12).

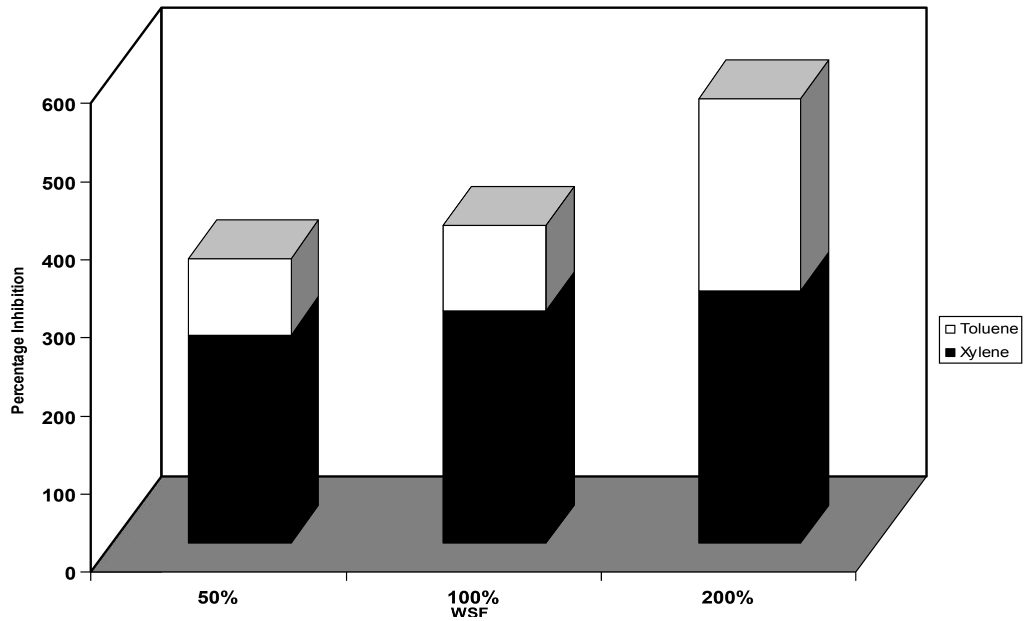
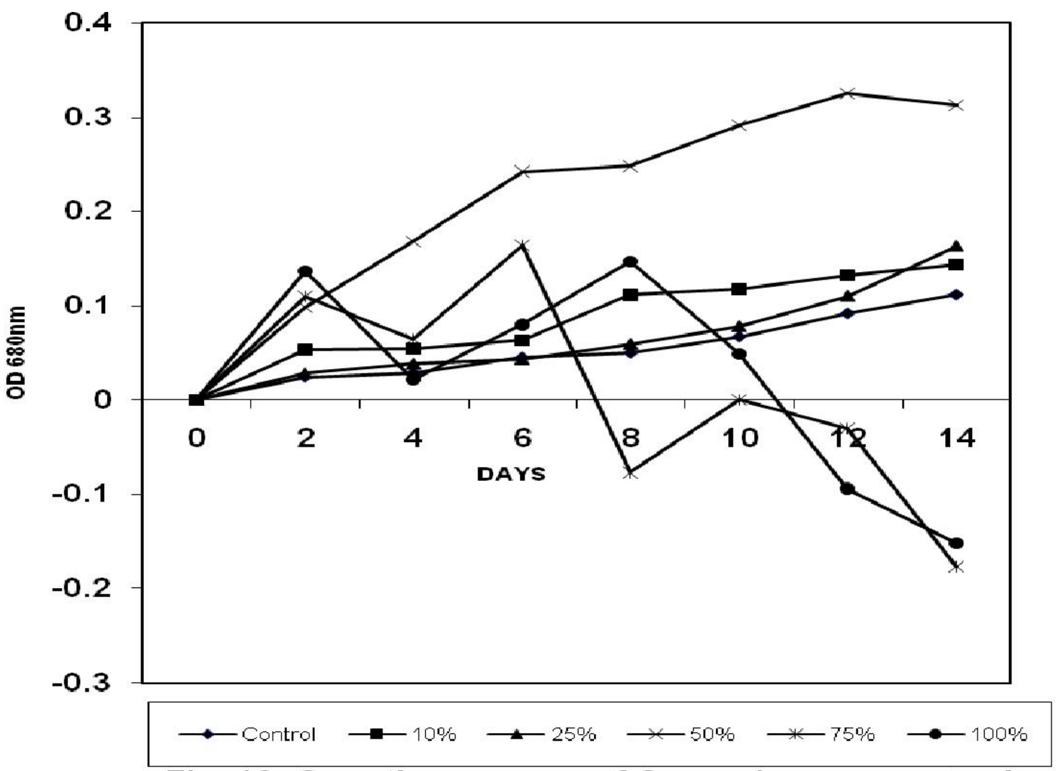


Fig 12. Comparative toxicities of Aromatic hydrocarbons to *Scenedesmus acutus*



Fig, 13. Growth response of *Scenedesmus acutus* in different concentrations of WSF of Bonny light Crude oil

Studies with Refined Petroleum Hydrocarbons

The effect of water soluble fractions of refined petroleum hydrocarbon (kerosene, diesel & petrol) was tested on some algae.

Studies with low concentrations of fuel oils (5-20%) were generally stimulatory to growth, especially in diesel and kerosene, with only minimal inhibition if at all (Kadiri & Enoma 2010).

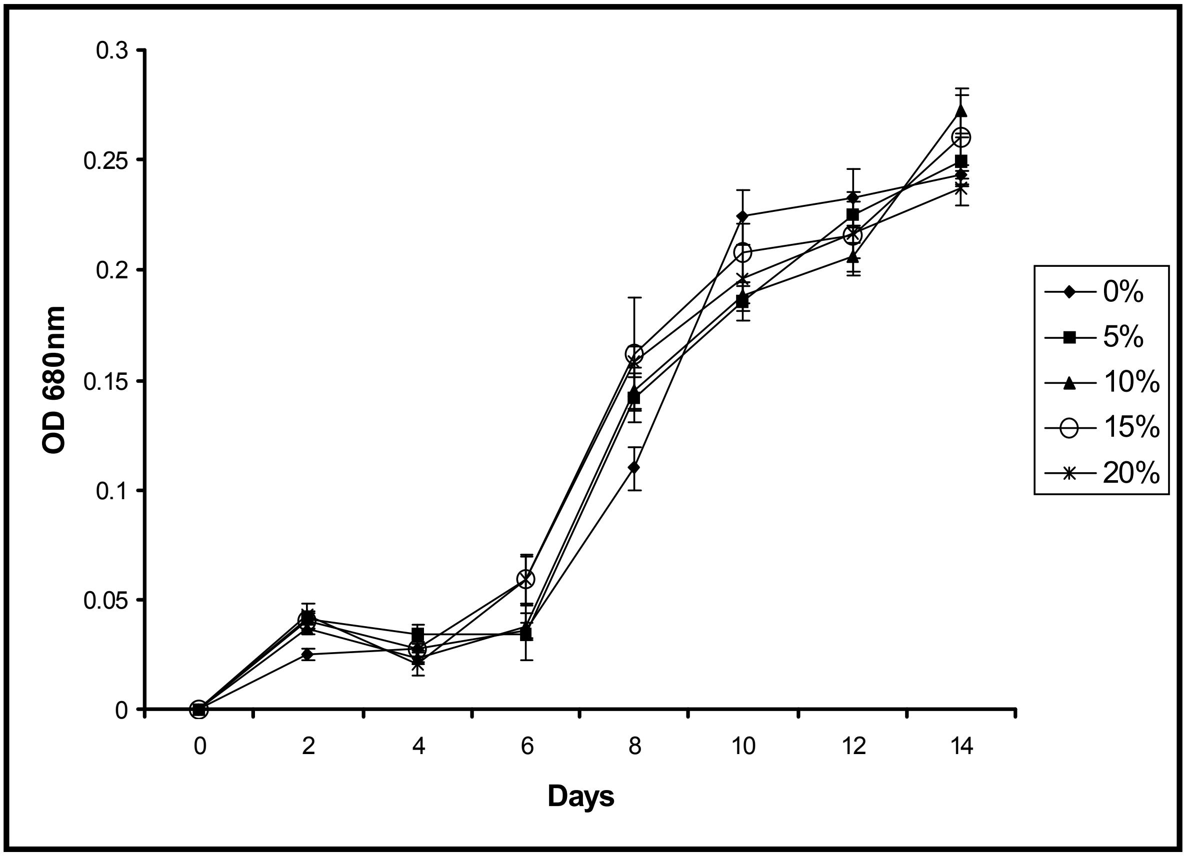


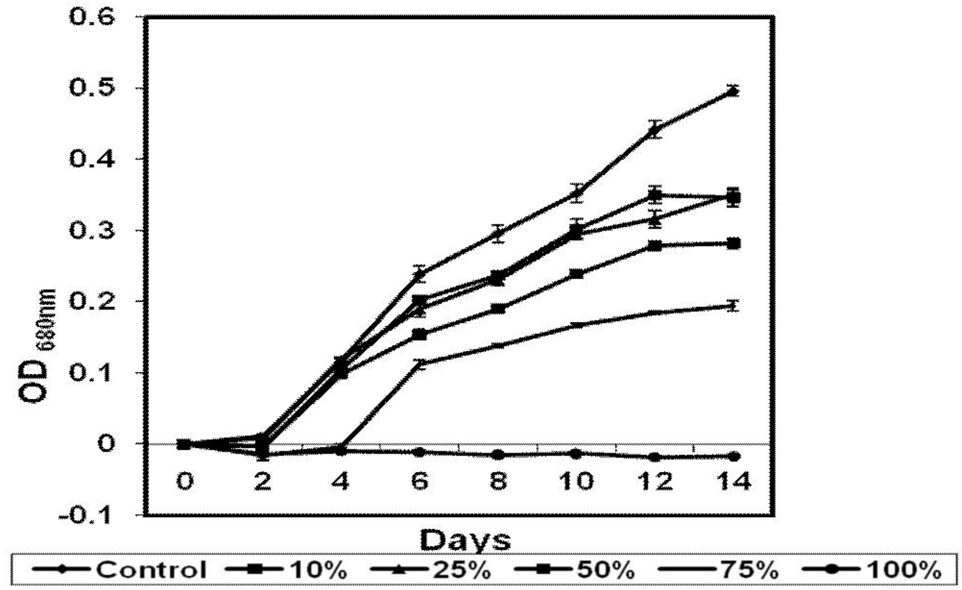
Fig. 14.Growth response of *Eudorina elegans* in Different concentrations of Diesel WSF

Following this result, we increased the concentration tremendously (25-100%) to observe the effects (Kadiri & Eboigbodin 2008).

For *Eudorina elegans,* in diesel, there was lag phase in control and lower concentrations (10% -50%) of test cultures from day 0 to day 2 and extended to day 4 for higher concentrations (75%-100%). Growth at 75% increased substantially after day 4. There was no significant difference between 10% and 25% concentrations. Growth at 100% was remarkably seriously inhibited.

The response of *Scenedesmus quadricuada* suggests that growth at 10 % and 25%

was highly stimulated while growth at 100% strongly inhibited.



Growth Response of *Eudorina elegans* in WSF of Diesel

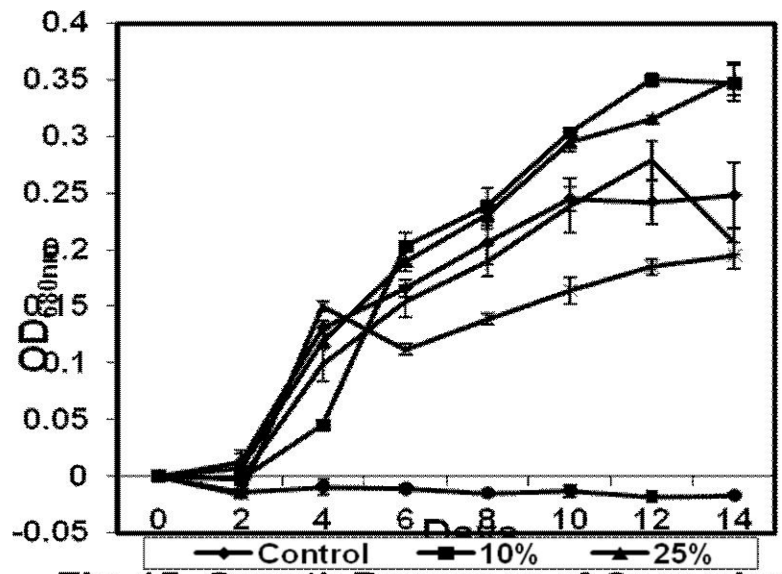


Fig. 15. Growth Response of *Scenedesmus quadricauda* in WSF of Diesel

A test of inhibition showed that the percentage inhibition increased with increasing WSF concentration and that hydrocarbons affected the different algae differently. In the case below, *Eudorina elegans* was more inhibited than *Scenedesmus quadricauda* which was in fact stimulated at lower concentrations of 10-25%.

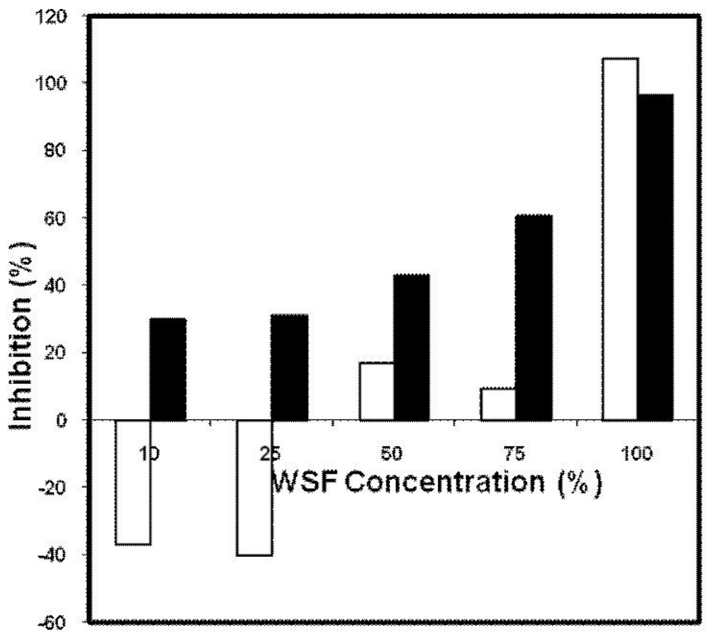


Fig. 16. Comparative Percentage Inhibition of test algae in Diesel

□ *Scenedesmus quadricauda* ■ *Eudorina elegans*

Effect of Crude oil, its water soluble fractions on algae: This study reveals stimulatory effects on micro-algae at low concentrations and inhibitory effects at high concentrations.

Results on Studies of the Phytotoxicity of Water Soluble (WSF) of Refined Petroleum products on algae could:

a. Assist in environmental management of the Niger Delta area and can be incorporated into environmental contingency plans by the oil companies.
b. Be important in selecting eco-sensitive regions of aquatic ecosystem and for preparedness and planning suitable response strategies whenever oil spill occurs.
c. Find application in oil spill modeling.
d. Provide a scientific basis for the evaluation of the consequences of oil pollution in the marine or aquatic environment in general

12) A New Technique

Comparative Methods for phosphate limitation detection in Microalgae
(Beardall, Berman, Heraud, Kadiri, Light, Patterson, Roberts & Sulzberger, 2001).
The use of emerging/novel techniques of Nutrient Induced Fluorescence Transients (NIFT) and Fourier Transform Infra Red (FTIR) spectroscopy was investigated to determine the nutrient status of microalgae under conditions where growth rate was P-replete or P-limited. This study was carried out in Switzerland (EAWAG). Laboratory cultures as well as natural lakes (Lake Lucerne & Lake Zurich) were used. The NIFT response and FTIR spectra was measured after P re-supply and they gave results consistent with those obtained by other conventional techniques (reduced photosynthesis, enhanced P-uptake etc). We showed that a NIFT response was evident in most P-limited algae and in natural phytoplankton population. Thus the NIFT approach is potentially very useful in exploring nutrient status of algae and their response to environmental change.

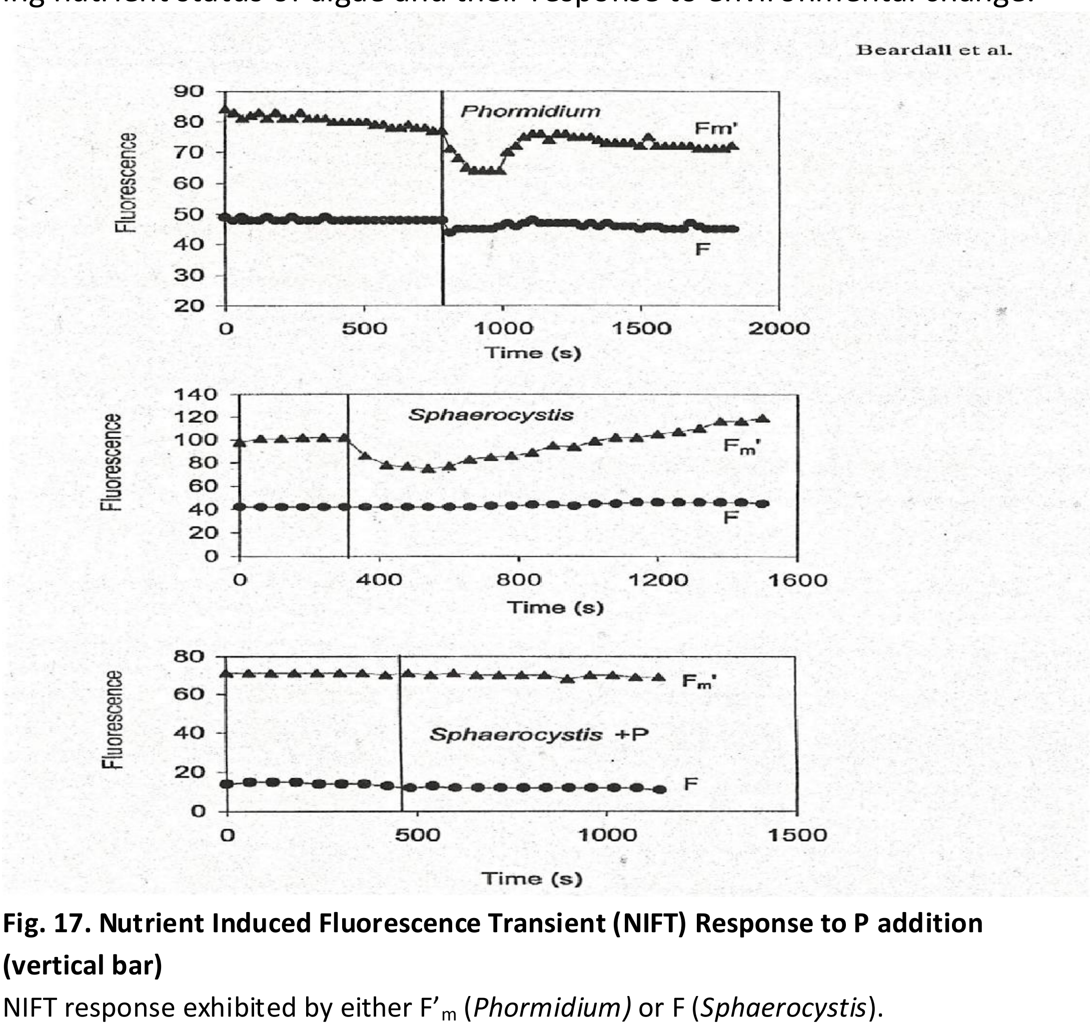


Fig. 17. Nutrient Induced Fluorescence Transient (NIFT) Response to P addition (vertical bar)

NIFT response exhibited by either F'_m (*Phormidium)* or F (*Sphaerocystis*).

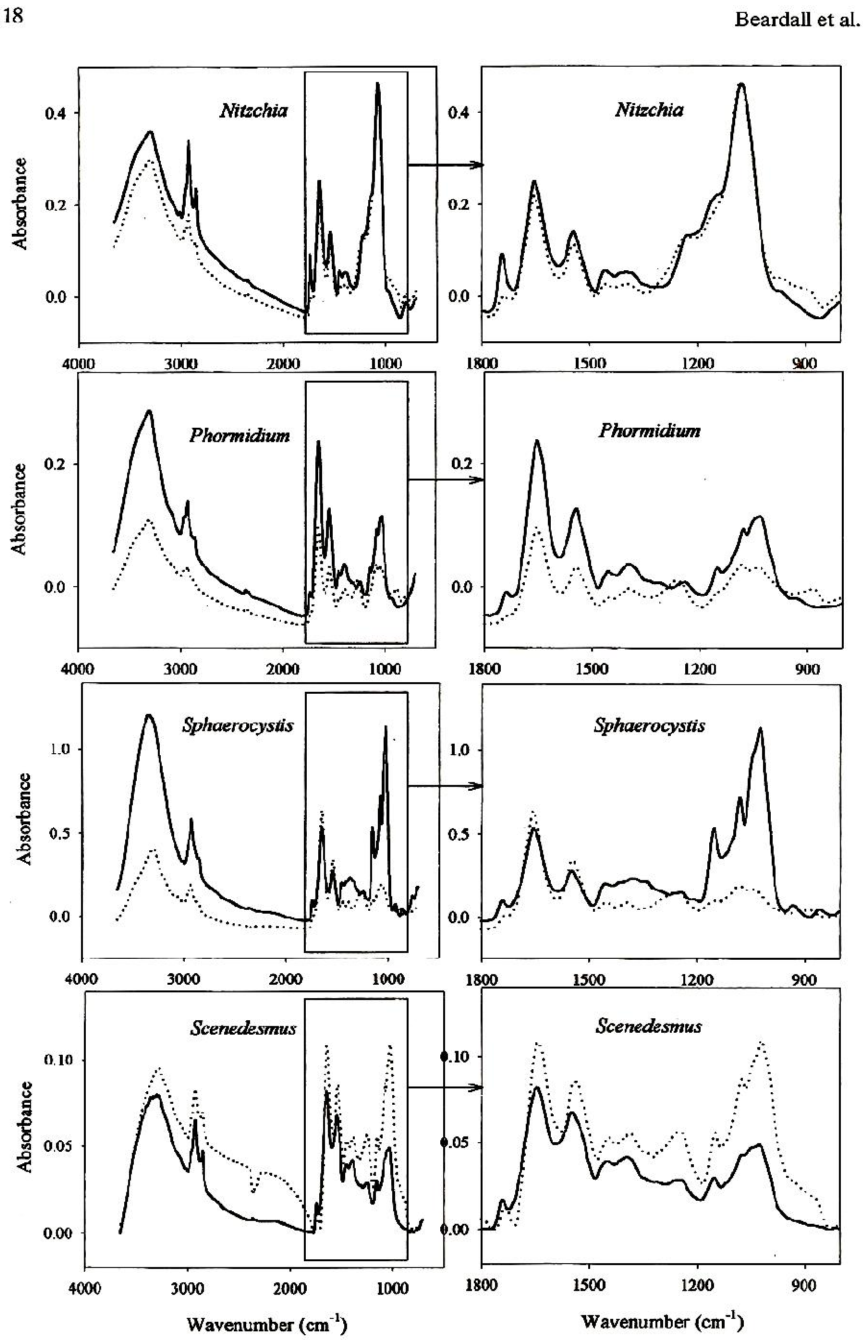


Fig. 18. FTIR-MS Spectra for test algae. Solid line represents spectra 'before' P supply

……….. represents spectra 'after' P supply

In all algae except *Scenedesmus*, re-supply of P caused a marked decrease in absorbance

The advantages of the fluorescent measurements include:

a) Rapid response
b) Highly sensitive (and accurate)
c) Non-destructive
d) Requires only small volume of samples
e) Can also be applied to natural populations of phytoplankton (algae)

Previous conventional techniques (e.g alkaline phosphatase activity, biomass, bioassays, elemental composition of algae, P-cell quotas, oxygen evolution and P-uptake capacity) used in determining factors limiting growth and production of algae suffer from deficiencies and /or artifacts. Most of these methods are complicated, time consuming and entail destruction of the sample.

Table 8 Comparison of conventional techniques of algal growth

Alga	Phosphorus quotas (pg/cell)			Maximum phosphorus uptake rate (pg P/cell/hr)			Maximum photosynthetic rate (nmol/min/ (10^6 cell)		
	Limited	Resupply	Δ%	Limited	Resupply	Δ%	limited	Resupply	Δ%
Sphaerosystis	0.5	7.4	1480	3.7	0.5	-86	2.3	8.1	352
Scenedesmus	1.7	46.1	2711	10.3	0.5	-100	17.4	96.9	554
Nitzschia	0.7	7.7	1100	1.7	0	-100	1.1	2.5	227
Phormidium	NA	NA	NA	0.92	0	-100	NA	NA	NA

Breakthroughs

Mr. Vice-Chancellor Sir, we have made modest contributions to knowledge in the following realm:

1) PIONEER RECORD OF ALGAE IN SOME NIGERIAN WATERS

2) FIRST NIGERIAN RECORD

- Kadiri (1988) recorded 33 taxa of *Closterium* as the first record in Nigeria.
- Kadiri & Opute (1989) 17 new record for the genus *Micrasterias.*
- 25 new species of *Cosmarium* previously unreported in Nigeria (Kadiri, 1993a).
- 21 new species of baculiform desmids belonging to the genera

Pleurotaenium, Gonatozygon,Groenbladia, Penium, Hyalotheca, Cylindrocystis, Tetmemorus and *Spiroteanium* (Kadiri, 1993b).

- Kadiri (1993c) also recorded 22 new taxa of *Actinotaenium, Arthrodesmus, Euastrum, Staurastrum* and *Staurodesmus.*

- Seven are new records of Chrysophytes for Nigeria (Wujek, Kadiri & Dziedzic 2009)

- First Nigerian record of algae in Ekpan Creek (Ugwu, 2008)
  Tryblionella levidensis Smith
  Psammothidium sp.
  Carpatogramma crucicula (Grunow) Ross
  Caloneis bacillum var *fontinalis* (Grunow)
  Diploneis puella (Schummon) Cleve
  Navicula schroeteri,
  Nitzschia heaflueriana (Grunow)
  Rhopalodia accuminata Kramer.

3) NEW RECORDS IN WEST AFRICA

- Kadiri (1996) reported 8 first records of *Actinotaenium, Arthrodesmus, Staurastrum* and *Staurodesmus.*

- Kadiri & Opute (1989) reported 8 taxa of *Micrasterias* as first record.

- Kadiri (1993a) lists 22 new records of *Cosmarium*

- Kadiri (1993b) reported 3 new records of *Pleurotaenium*

4) AFRICAN NEW RECORDS

- Six are new African records of Chrysophytes (Wujek, Kadiri & Dziedzic 2010).

  These are:

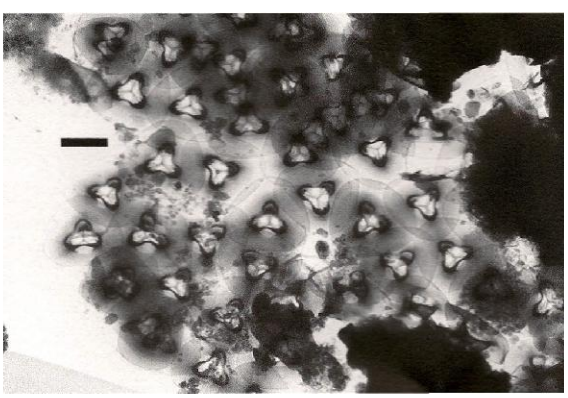
Mallomonas doignonii var. *doignonii* Bourrelly em. Asmund & Cronberg
(collected from Ovia River)

M. parvula Dürrschmid (collected from OkomuRiver)
M. paxillata (D.E. Bradley) L.S. Péterfi & Momeu (collected from Ogbese River)
Mallomonas sp. 3(collected from Orionmwon River)
Mallomonas sp. 4 (collected from Gelegele River)
Synura leptorrhabda (Asmund) K.H. Nicholls in K.H. Nicholls Gerrath (collected from Ugonoba River)

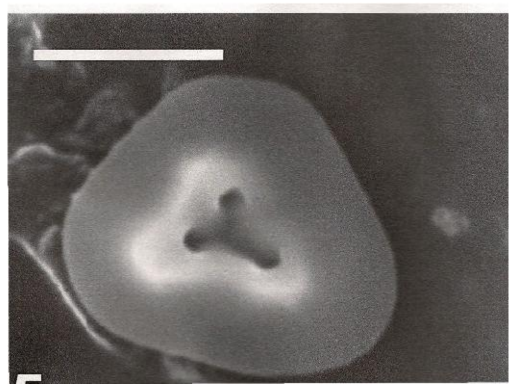
5) WORLD RECORD (A NEW SPECIES TO SCIENCE)

The following is a new record to science
Using Transmission Electron Microscope, we described a new freshwater species from Nigeria named *Thaumatomastix nigeriensis* Wujek, Pershon et Kadiri nov. spec (Wujek, Pershon & Kadiri 2008) collected from Okomu Forest lake and pond
Diagnosis: Cells solitary, c. 7 x 15 µm, with two flagella. The long flagellum is apparently naked, c. 12 µm. The cell body is covered by scales of one type. The solid base plate is triangular with rounded corners (scale: 1.4-1.9 µm from one rounded corner to the center of the scale's edge on the opposite side; edge: 0.34-0.36 µm; n = 14). A conspicuous tri-lobed projection (0.65-0.85 µm) is centrally placed. Three struts unite in the center of the scale's central projection. They are formed by the fusion of material arising from the bases of the tri-lobed central projections. Three large pores, one each at the narrowest portion of the central projections, are located at the thinnest portion of each central projection and between the struts.

The central portion of *T. nigeriensis* possesses three pores, one at the base of each sinus region whereas in the other nearest two taxa (*T. triangulata* & *T. tripus*) the pores are smaller and more marginally placed.
The scales of our species lacks a supporting a superstructure
Material is currently deposited in the Central Michigan University, U.S.A. herbarium, with accession number CMC 17557



TEM micrograph of *Thaumatomastix nigeriensis*:a group of Body scales: Scale bar =1 µm



SEM micrograph of *Thaumatomastix nigeriensis:* body scale . Scale bar = 1µm

Generally, the genus *Thaumatomastix* at present comprise 14 species none of which has been reported in Africa

CHALLENGES

Mr. Vice-Chancellor Sir, during the period of our research, we encountered numerous changes which can be summarized into the following groups:

- Occupational hazard
- Lack of equipment
- Inadequate funding
- Lack of encouragement by the university. (Delayed promotion despite hard work and excess number of publications in good quality international journals)

RECOMMENDATIONS

I wish to recommend as follows:

- Establishment of "Algal Culture Collection Center" to produce National Bank of Algae.

  Culture collection is a valuable source of research material for scientific studies, especially Taxonomy, Genetics, Evolution, Biotechnology, Physiology, Ecology, Environmental and Engineering (Environmental, Chemical), Physics, Biochemistry etc. The functions of Culture collection is that they are a warehouse or depot for traceable information and live materials of good and definite quality and consistency against which biological standards are assessed and compared. Cultures or material which would have been otherwise problematic to re-isolate from their natural habitats or known source can be easily held at culture collection centers. They provide a biological store of charaterised species diversity needed for research, future exploitation and subsequently, the overall goal of sustainable development.

  In the African continent, culture collection centers are found only in Egypt, Morocco (bacteria, yeast, other fungi) and South Africa (bacteria and fungi), Senegal (algae-only 10, and bacteria), Uganda (Trpanosomiasis), Zimbabwe (viruses, fungi, Protozoa & Bacteria-*Rhizobium*).

The culture collection proposed for the University of Benin will represent Biological Resource Center in Nigeria, West Africa sub-region and the African continent. Having worked in a culture collection center in United Kingdom, I have the technological know –how. All that is needed is a room and funding.

- Entrepreneurial Phycology

  This is a situation whereby commercial products can be prepared from algae and sold. For instance, 1 ton of alginate from sea weed cost $6000-10,000 per ton (Bruton *et al.*, 2009).

  Algal products constitute multibillion dollar industries in developed countries. Nigeria should not be left out of this 'Green Gold Mine'. Nigeria should exploit her seaweeds for commercial products for export. Funds should be provided to establish 'Entrepreneurial Phycology'. Many students will be interested in this.

- A Phycological Herbarium can also be established here at the University of Benin. This would include reproducing the "Fritsch Collection of Algal Illustration". It will serve as a repository for type- or iconotype forms against which identification can be made, compared or confirmed. The original Fritsch Collection is held at the Freshwater Biological Association, Windermere, England. It is a unique herbarium collection containing floristic information, illustrations, identification and taxonomy of worldwide freshwater and terrestrial algae. The Collection was begun in 1912 by Professor Felix Eugene Fritsch and has been expanded and updated to date. It contains millions of illustrations and researchers from all over the word travel there to consult it for identification of algae. If we have a similar collection at the University of Benin, it will serve researchers from all over Nigeria and West Africa and even beyond.

- Use of algae as a renewable alternative energy source in the production of biofuel should be explored.

- More Phycologists are required in Nigeria
- For the University administration, I strongly recommend that the assessment of lecturers for the position of Professor should not exceed one year.

CONCLUSION

Mr Vice-Chancellor Sir, I have attempted, in this lecture, to x-ray the importance of algae and to arouse sufficient interest both in the subject area and utilization of algal products. I have discussed our work on the classic or fundamental study of algae as well as the applied aspects. Our work has provided the much needed and otherwise previously unavailable reference materials to prospective Phycologists, other researchers and students.

I have shared our work on emerging/novel technique in the area of environmental change, employing algal response. The exploitation of algal resources for commercial products and as alternative sources of energy is strongly advocated. Nigeria should key in to the money-spinning industry as is done in other parts of the world.

In this lecture, I have highlighted some algal species which are first record in Nigeria, West Africa, Africa and the world.

Phycologists are needed in many other Nigerian universities and to undertake research in the numerous, yet un-researched aquatic environments in the country, for therein may lie many other new species to science. Finally, I have made some suggestions some of which will make the University of Benin the hub of algal research in West Africa and Africa such as the establishment of Algal Culture Collection Center and Algal herbarium.

Mr. Vice-Chancellor Sir, where ever there is water, no matter how brief, there is a phycological story (to tell). My business was to find the story and tell it as it is. In doing so, I have collected algal samples from South, East and west of Nigeria, taken them beyond the shores of Nigeria to USA, U.K, Switzerland, India etc to be able to tell a complete story.

WITH ALGAE, WE CAN HAVE CLEANER ENERGY, CLEANER ENVIRONMENT AND COOLER CLIMATE

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