Assessment of macrozoobenthos in Bodo Creek: A Review

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Abstract— Macrozoobenthos are animals that live in or on the bottom substrates including sediments, rocks, snags and aquatic plants, of aquatic ecosystems for at least part of their life cycle. They can be seen with the naked eye and usually greater than 0.5mm in diameters. They include aquatic worms (flatworms, eelworms and segmented round-worms) and premature forms of marine insects such as stonefly and mayfly. Others are crayfish, molluscs such as clams, bivalves and snails. These organisms are relatively immobile which compromises their ability to avoid the impact of pollution in water habitats. This review further identified three features which makes them suitable as bioindicators to include; (i) exposure to chemical contaminants mostly accumulated in sediment, (ii) exposure to dissolve oxygen levels that are low (hypoxia/anoxia) that often occur close to the bottom surface as a result of organic matter degradation, (iii) taxonomic diversity and functions that make them suitable for the detection of different types and levels of stress. They play key roles in energy fluxes and nutrient cycling; grazing ability (and in some areas may prevent blooms), assist in organic matter breakdown and cycling of nutrients and, in turn, may become food for predators. Two major oil-spills took place in Bodo Creek in 2008, which necessitated clean up in the oil-spill impacted creek. The review however identified four stages in the life of macrozoobenthos in the area to include; pre-spill, post-spill, natural recovery and clean-up recovery stages. The review concludes that although natural attenuation can lead to the recovery of damaged habitats including lost species post-spill, it is better to carry out cleanup for faster and better recolonization of oil-spill impacted sites.

Keywords—Aquatic environment, bioindicators, clean-up,macrozoobenthos andoil-spill

1.0 INTRODUCTION

1.1 Bodo Creek

Bodo is a coastal community located in Gokana Local Government Area, Ogoni in Rivers State, Nigeria. Other Local Government Areas that make up Ogoni are Khana, Tai and Eleme. Politically, the Bodo community is in the South East Senatorial District of Rivers State. Bodo is a rural community occupying (latitude 4836′N, longitude 7821′E) in the upper reaches of Andoni-Bonny estuarine ecosystem. Mangrove swamps, some island forests and brackish water creeks occupy over 65% of the community. This is generally called Bodo Creek. Every day, the creeks in Bodo are exposed and submerged due to the influence of low and high tide, respectively. The community is divided into 35 villages under the leadership of a monarch king and his council of chiefs[1].In 2008, two major oil-spill occurred in Bodo Creek. Post-spill study [2] revealed a sharp decline in the total population and abundance of macrozoobenthos from the pre-spill studies on the creek [3], [4].

1.2 Biological Communities

Environmental factors help to structure biological communities [5]. This is, in addition to the effect of interactional relationship, among or between individuals and groups that form a part of the populations, assemblages, communities and ensembles [6].Species vary in how much they tolerate changes in the environment with the result that under polluted condition, a decrease in diversity of species is the commonly noticed effect. Fish, the vertebrate that has the highest population in the aquatic environment, occupying the highest trophic levels of food chains in the ecosystem are also affected by serious organic and inorganic pollution [7]. Several investigators have advocated for the use of invertebrates and fish as biological indicators of the quality of water. For instance, a Tubifex and Chironomus species dominated environment is a reflection of a low oxygen concentration and high organic enrichment. A clean stream naturally would be dominated by an association of mayflies, stoneflies and caddis flies [8]. The negative impact of pollution on water quality which consequently affect the abundance, species composition, diversity of macro-invertebrate and fish fauna pose a great threat to the sustained existence and preservation of water bodies in Nigeria [8]. The effects of organic pollution on macroinvertebrate communities have been greatly investigated [9].

2.0 MACROZOOBENTHOS

2.1 Basic Description of Macrozoobenthos

These are animals >0.5mm that live in the bottom substrates including sediments, rocks, snags and aquatic plants, of aquatic ecosystems for at least part of their life cycle [10]. They can also live on the substrates [11]. These aquatic organisms are a diverse array of fauna with or without backbones. They are retained by sieve or mesh with pore size of 0.5mm, most frequently used in stream sampling devices [12]. Macrozoobenthos, are usually larger than 0.5millimeter (the size of a pencil dot). Sometimes they can be found on sediment, while at other times they can be partially/wholly buried in the sediment of the sea bottom. These organisms include a diverse assemblage of fauna across nearly all the animal phyla. Macrozoobenthos are aquatic animal which inhabit the bottom of marine and fresh waters, with size greater than 0.5mm in diameters [13]. They live on rocks, logs, sediment, debris and aquatic plants throughout or some parts of their lifespan. Benthic macrozoobenthos could be littoral or profundal [14].

2.2 Characteristics of Macrozoobenthos

Some benthos shuttle between water and moist terrestrial ecosystems such as freshwater snail. They can be classified based on the substrate they occupy into in-fauna and epi-fauna [15]. Benthic animals that live either buried or burrowed into the sediment make up the in-fauna. Those that live on the surface of sediments make up the epi-fauna. They are usually found attached to exposed or submerged object, some move slowly while others live a sedentary life.

It is easy to monitor them because they can be sampled quantitatively and also respond to anthropogenic disturbances [16]. They have low mobility which compromises their ability to avoid the impact of pollution in their habitats. This makes them to be often used as bio-indicators to monitor pollution. Also, one of the characteristics of benthos is that they are easily obtained, are diverse, and are sensitive to a variety of water disturbances. The condition of aquatic habitat can be described by macrozoobenthos community [17]. Macrozoobenthos are limited in their mobility and may not readily avoid pollutants. As a result, they are widely used as biological indicators.

They are widely used for environmental monitoring because they have contact with both water column and sediment covering the ocean floor and are sensitive to toxic compounds in both.

Sensitivity is widely expressed as an alteration in reproduction, growth rate, or mortality, in addition to changes in species distribution [18].

2.3 Common Examples of Macrozoobenthos

The macrozoobenthos, which live near, in or on substratum of running water, is made up of representatives of nearly every taxonomic group that occurs in water. Remarkably, there are few freshwater groups which are not regularly represented in rivers. On the other hand, there are many groups which occur in running water, and many attain their highest development and diversity there [19], [20]. Some examples of macrozoobenthos include crayfish, molluscs such as clams and snails, aquatic worms and premature forms of marine insects such as stonefly and mayfly (Nkwoji *et al.*, 2010). Macrozoobenthos in stream include different groups of worms (flatworms, eelworms and segmented round-worms), molluscs (snails and bivalves), crustaceans (shrimps, crayfish and other shrimp-like groups), mites, and above all insects (Winterbourn, 1999). Many bottom-dwelling macro-invertebrates are larval form of flying insects such as mayflies, stoneflies, caddisflies, midge flies etc. insects are the most diverse group of freshwater benthic macrozoobenthos; others are small fauna that spend their entire life in streams for example mites and planarians.

2.4 Roles of Macrozoobenthos in Aquatic Environment

Aquatic macrozoobenthos are an important component in the ecological dynamics of lotic environments. They play critical roles in energy fluxes and nutrient cycling. These organisms are also commonly used in biomonitoring [21].Many invertebrates are important components of stream ecosystems. They have grazing ability (and in some areas may prevent blooms), assist in organic matter breakdown and cycling of nutrients and, in turn, may become food for predators [22]. These organisms are the most widely used for biological monitoring of freshwater environments worldwide. This is due to their presence in most habitats. They also have limited mobility, can be easily collected following established standard techniques, and diversity of forms that ensures a wide range of sensitivities to alterations in both water quality (of virtually any nature) and habitats [23], [24].

Most bottom dwelling organisms feed on debris that settle on the bottom of the water and in turn serves as food for a wide variety of fishes [25]. They also have the ability to accelerate the breakdown of decaying organic matter into simpler inorganic forms such as phosphates and nitrates [26]. The most popular biomonitoring method in freshwater bodies receiving domestic and industrial wastewaters is the use of bottom dwelling macrozoobenthos [27]. Water quality has a great influence on their composition, abundance and distribution [28]. In the benthos, different processes such as feeding, nesting and burrowing are influenced by several grades of sediment particles. Therefore for aquatic organisms such as bottom-dwelling macro fauna, the nature of the bottom is important to their ecology.

These organisms form part of the aquatic food chain and they are also used to assess water quality and as indicators of pollution. They form a link between nutrients and detritus and important protein materials in shellfish and fish. Their sedentary lifestyle makes it possible for them to easily imbibe and accumulate any xenobiotic compounds and other stressors present in the water body [29]. Consequent upon the often difficult attempt to monitor disease outbreak and spread directly, or even longevity in natural populations and even human communities, indicators of environmental status including macrobenthic fauna are often used as surrogates to reduce the difficulty in monitoring disease outbreak[30]. In the selection of a biological component for sediment contamination assessment, bottom dwelling invertebrates have proved to be very useful. Field surveys of invertebrates (as well as vertebrates) provide an essential component of biological assessments of toxicity associated with sediment contamination [31].

As a result of their wide diversity, longevity, sensitivity, and important roles in the function of the ecosystem, they give excellent model systems for the examination of the effects of man-made disturbances on aquatic ecosystems [32].

2.5 Macrozoobenthos as Bioindicators

Benthic macrozoobenthos are the most widely used tool in biological monitoring. All the substances (pollutants) that enter the aquatic ecosystem either sink or settle down to bottom/sediment with time, implying that the sediment or organisms that live there keep the longest and best account of activities both natural and man-made [33]. Bottom dwelling in-fauna are especially suitable as ecological indicators as a result of their habitat preference and relatively low ability to move and are thus affected directly by substances that enter the environment. Macrozoobenthos are important bioindicators that provide a more accurate understanding of changing aquatic conditions than chemical and microbiological data, which mostly give short-term fluctuations [34].

The condition of aquatic habitats can be ascertained through the study of macrozoobenthos community structure (Dar *et al*., 2010). The structure of macrozoobenthos community can be described by its species diversity and abundance. Bottom dwelling aquatic organisms are commonly used as indicators for the assessment of pollution impacts in ecosystems. The most important advantages of using benthos as bioindicators have been summarized by a several authors [35]. Benthic community is made up of several representatives from different orders. There is the assumption that such a range of species gives significant probability of sensitive species being present; spatio-temporal mobility of species is restricted, therefore they can be regarded as inhabitants of the aquatic system under investigation; the life of organisms reflects environmental conditions over long periods of time [36].Studying macrozoobenthos diversity is one of the most effective and less expensive ways to estimate the ecological quality of the waters [37].For example, physico-chemical measurement of water can be used to estimate its quality but such measurements cannot completely be a representative of the real state of the waters. Therefore, it is of necessity to combine physical, chemical and biological assessment in addition to other monitoring methods to provide a comprehensive picture of environmental water quality. The use of macrozoobenthos in biological monitoring has been found accurate and advantageous in comparison with other organisms because they are extremely sensitive to organic pollutants, widely distributed and can be easily and economically sampled. Reports from scientific investigations on the use of macrozoobenthos in the evaluation of the quality of water in aquatic ecosystems have been extensively published by several scientists.

Advantages abound on the use of benthic macrozoobenthos in the evaluation of water quality. Bottom dwelling macrozoobenthos are ubiquitous in rivers and thus can be under the influence of environmental disturbances in several different types of aquatic systems and in most habitats/biotypes within these waters [10]. These organisms are largely immobile and therefore adequately represent the location being sampled. They have a long life-span that allows for the elucidation of changes in time following disturbances, while short enough to allow for observation of recolonization patterns as a result of such perturbation. They are easy to sample and identify. Macrozoobenthos act as continuous monitors of the water in which they live [38], allowing for long-term analysis of both regular and intermittent discharges, changes in pollutants concentrations, single and multiple pollutants and synergistic or antagonistic effects. Using fauna as bioindicators of environmental stress has proven successful and indices based on macrozoobenthos composition have proven to be useful measures of the health of a river and are applied widely today [39,40].

Benthic communities are mostly used as bioindicators due to their ability to provide information on the conditions of the environment either as a result of the sensitivity of single species (indicator species) or maybe due to some general feature that makes them integrate environmental signals over a long period of time. The features includes: (i) exposure to chemical contaminants mostly accumulated in the sediment, (ii) exposure to dissolve oxygen levels that are low (hypoxia/anoxia) that often occur close to the bottom surface as a result of organic matter degradation, (iii) diversity in their taxonomy and functions that make them suitable for the detection of different types and levels of stress [41].

Table 1:Trend OfMacrozoobenthos In Bodo Creek

S/N	Reference(s)	No. of species
1	[2]	22
2	[2]	18
3	[42]	36
4	[3]	47
5	[4]	18
6	[2]	4
7	[43]	6
8	[44]	11
9	[45]	18

3.0 STUDIES IN BODO CREEK

3.1 Pre-spill Study

Before the two major oil-spill in Bodo creek in 2008, several studies were carried out to assess the abundance and distribution of macrozoobenthos in the creek. A pre-spill assessment of macrozoobenthos in Bodo Creek in 2006, identified 462 individuals from 4 classes, 15 families, 17 genera and 22 species [2]. Another study on macrozoobenthos in the creek in 2007, identified a total of 264 individuals from 4 classes, 13 families, 14 genera and 18 species were identified [2]. In a study on the tree fauna of Bodo creek which produced a preliminary checklist of macrozoobenthos of the creek by Zabbey and Hart [3], they identified 7742 individuals, from 4 classes, 29 families, 38 genera and 47 species. Zabbey and Malaquias [4] while working on the epifaunal macrozoobenthos of Bodo creek between 2006 and 2008 reported a total of 601 individuals from 4 classes, 14 families, 15 genera and 18 species. According to Zabbey and Arimoro [42], between 2006 and 2007, 3333 individuals, from 4 classes, 22 families, 28 genera and 36 species were identified in Bodo Creek; while working on environmental forcing of intertidal benthic macrofauna of Bodo Creek, Nigeria.

3.2Post-spill Study

Several studies have been carried out to assess the impact of the 2008 – 2009 oil-spill on macrozoobenthos in Bodo Creek.In a study on macrozoobenthos in Bodo Creek conducted in July, 2011 by Zabbey and Uyi [2], they identified only 169 individuals representing 2 classes, 3 families, 4 genera and 4 species. In 2013 6 species of macrozoobenthos were identified in Bodo Creek [43]. Between 2015 and 2016, 11 species of macrozoobenthos were identified in Bodo Creek [44].

3.3 Clean-up Study

Following the two major oil-spills that occurred in Bodo Creek in 2008, there was need for a clean-up of the oil-spill impacted creek. Bodo Creek clean-up commenced in September, 2019. Following the clean-up, Nkeeh [45] assessed the impact of the oil-spill clean-up on macrozoobenthos in the creek. The study identified a total of 18 species.

A critical evaluation of these studies on the creek reveals four stages in the life of macrozoobenthos in Bodo Creek. Firstly, the pre-spill stage that was characterized by the abundance of macrozoobenthos. This was followed by a post-spill stage where most of the species that previously occupied the creek were lost due to the presence of hydrocarbon in the environment. The third stage was the natural recovery stage, where some of the species previously lost due to the oil-spill were gradually emerging in the creek. The clean-up stage was the last stage. In this fourth stage, there was relatively higher species richness and diversity of macrozoobenthos in the creek than previous evaluated post spill records.

4.0 Conclusion

Although natural attenuation can lead to the recovery of lost species post-spill, human-aided cleanup achieves faster and better recolonization of oil-spill impacted sites.

References

[1] Onwugbuta-Enyi, J., Zabbey, N. and Erondu, E. S. (2008). Water quality of Bodo Creek in the lower Niger Delta basin. Adv. Environ. Biol. 2, 132–136.

[2] Zabbey N. andUyi, H. (2014). Community responses of intertidal soft bottom macrozoobenthos to oil pollution in a tropical mangrove ecosystem,NigerDelta, Nigeria. Mar Pollut Bull 82:167–174 https://doi.org/10. 1016/j.marpolbul.2014.03.002

[3] Zabbey, N. and Hart, A.I. (2011). Preliminary checklist of macrozoobenthos of Bodo Creek in the Niger Delta, Nigeria. Nigerian J. Fish. 8 (2), 271–283.

[4] Zabbey, N. and Malaquias, M.A. (2013). Epifauna diversity and ecology on intertidal flats in the tropical Niger Delta, with remarks on the gastropod species Haminoeaorbignyana. J. Mar. Biol. Assoc. UK 93, 249–257.

[5] Miserendino, M.L. (2001). Macroinvertebrate assemblages in Andean Patagonian rivers and streams: environmental relationships. Hydrobiologia (444):147–158.

[6] Fauth, J.E., Bernardo, J., Camara, M., Resetarits, W.J., Van Buskirk, J. andMcCollim, S.A. (1996). Simplifying the jargon of community ecology: a conceptual approach. Amer. Nat. 147:282–286.

[7] Sikoki, F. D. and Kolo, R. J. (1993). Perspective in water pollution and their implications for conservation of aquatic resources. Proceedings of the Nationalconference on aquatic resources. (ed)nEgborge, A. B. M., Omoloyin, O. J., Olojiede, A. and Mani, S. B. National Resources conservation council, Abuja, 318p.

[8] Akponine, J. A. (2016). Physico-chemical parameters, plankton, macrozoobenthos and fish fauna of Ibuya River, Sepeteri, South-Western Nigeria (Ph.Dthesis), University of Ibadan, Oyo State, Nigeria.

[9] Umesi, N. and Daka, E. R. (2004). Effects of abattoir run-off on benthic populations in a tidal creek in the Upper Bonny Estuary. J. Environ. Manage. Educ., 1:158-170.

[10] Sengupta, M. and Dalwani, R. (2008). Benthic invertebrates – A crucial tool in biomonitoring of lakes. Proceedings of Taal 2007: The 12th world lake conference: 95-98.

[11] Nupur, N., Shahjahan, M., Rahman, M.S. and Fatema, M.K. (2013). Abundance of macrozoobenthos in relation to bottom soil textural types and water depth in aquaculture ponds. International Journal of Agricultural Research, Innovation and Technology 3 (2): 1-6.

[12] Winterbourn, M. J., Rounick, J. S. and Cowie, B. (1999). Are NewZealandstream ecosystems really different? N. Z. J. Mar. Freshwater Res. 15:321-328.

[13] Nkwoji, J. A., Yakub, A., Ajani, G. E., Balogun, K. J., Renner, K. O., Igbo, J. K., Ariyo, A. A. and Bello, B. O (2010). Seasonal variations in the water chemistry and benthic macroinvertebrates of a south western Lagoon, Lagos, Nigeria. Journal of American Science 2010; 6(3): 85-92.

[14] Mann, K.H. (1980). Benthic Secondary production in: Mann, K.H et al (Ed) (1980) Fundamentals of aquatic ecosystems. Pp. 103-188.

[15] Cody, M. L., and Diamond J. M. (1975). Ecology and Evolution of Communities. Belknap Press of Harvard University . 543pp.

[16] Otway, N. M. and Gray, C. A. (1996).Assessing the impacts of deepwateroutfalls on spatially and temporally variable marine communities. Mar.Environ. Res.Oxford.41:45-71.

[17] Dar, I. Y., Bhat, G. A. and Dar, Z. A. (2010). Ecological distribution of macrozoobenthos in Hokera Wetland of J&K, India. Journal of Toxicology andEnviromental Health Sciences 5: 63-72.

[18] Nkwoji, J. A. and Edokpayi, C. A. (2013). Hydrochemistry and community structure of benthic macroinvertebrates of Lagos Lagoon, Nigeria. Research Journal of Pharmaceutical, Biological and Chemical Sciences, 4(1):1119- 1131.

[19] Hynes, H. B. N. (1970). The Ecology of Running Waters. Liverpool University Press, England. p. 555.

[20] Allan, J. D. (1995). Stream Ecology: Structure and Function of Running Waters. Chapman and Hall, New York, pp. 388.

[21] Karina, O. R., Kennedy, F. R., Otavio, F. and Marcel, R. C. (2010). Structure of macroinvertebrate communities in riffles of a Neotropical Karst stream in the wet and dry seasons. Acta LimnologicaBrasiliensia, 22(3): 306-316.

22] Hussain, Q. A. and Pandit, A. K. (2012). Macroinvertebrates in streams: A review of some ecological factors. International Journal of Fisheries and Aquaculture, 4(7):114-123.

[23] Hellawell, J. M. (1986). Biological Indicators of Freshwater Pollution and Environmental Management. Elsevier, London, pp. 518.

[24] Abel, P. D. (1989). Water Pollution Biology. Ellis Horwood, Chichester, UK, pp. 232.

[25] Idowu, E. O. and Ugwumba, A. A. (2005). Physical, chemical and benthic faunal characteristics of a Southern Nigeria Reservoir. The Zoolog.. 3: 15-25.

[26] Gallep, G. W., Kitchell, J. F. and Bartell, S. M. (1978). Phosphorous release from lake sediments as affected by chronomid. Ver inter ver for Limnonogy, 20:458-465.

[27] Odiete, W. O. (1999). Environmental physiology of animals and pollution. Diversified Resources, Lagos, Nigeria. 26pp.

[28] Onyena, A. P. (2019). Composition, Distribution, and Diversity of Benthic Macroinvertebrate from Creeks around Lagos Lagoon, Nigeria. J. Appl. Sci. Environ. Manage, 23 (5): 857-863.

[29] Chaphekar, S. B. (1991). An overview on bio-indicators. J. Environ. Bio.12: 163-168.

[30] Post, A. L. (2006). Physical surrogates for Benthic organisms in the Southern Gulf of Carpentaria, Australia: Testing and Application to the Northern planning area. Geoscience Australia, Canberra. 6pp.

[31] Canfield, T. I., Kemble, N. E. C. and Brumbungh, W. G. (1994).Use of Benthic Invertebrate Community Structure and the Sediment Quality Traid to Evaluate Metal-Contaminated.Sediment in upper Clark fork River, Montana Environ Toxicol. Chem.,13, 1999-2012.

[32] Wokoma, O. A. F. and Umesi, N. (2017). Benthic macro-fauna species composition and abundance in the Lower Sombreiro River, Niger Delta, Nigeria. European Journal of Biology and Medical Science Research. 5(1):17-23.

[33] Wokoma, O.A. F. and Mgbomo, T. (2013).Biological Response Signatures of Marine Organisms in Pollution Monitoring.NERJHESD. 6 (1), 1-12.

[34] Ikomi, R. B., Arimoro, F. A. and Odihirin, O. K. (2005). Composition, distribution and abundance of macroinvertebrates of the upper reaches of River Ethiopia, Delta State, Nigeria. The zoologist, 3:68-81.

[35] Rosenberg, D. M and Resh, V. H. (1993). Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall. 488pp.

[36] Uwadiae, R. E (2016). Benthic macroinvertebrate community and chlorophyll a (chl-a) concentration in sediment of three polluted sites in the Lagos Lagoon, Nigeria. J. Appl. Sci. Environ. Manage. 20 (4) 1147-1155.

[37] Patang, F., Soegianto, A. and Hariyanto, S. (2018). Benthic macroinvertebrates diversity as bioindicator of Water quality of some rivers in east kalimantan, Indonesia. International Journal of Ecology Volume 2018, Article ID 5129421, 11 pages https://doi.org/10.1155/2018/5129421.

[38] Kalyoncu, H. and Zeybek, M. (2011). An application of different biotic and diversity indices for assessing water quality: A case study in the Rivers Çukurca and Isparta (Turkey). Afr. J. Agric. Res., 6(1): 19-27.

[39] Omoigberale, M. O. and Ogbeibu, A. E. (2010). Environmental Impact of Oil Exploration and Production on the Macrobenthic Invertebrate Fauna of Osse River, Southern Nigeria. Research Journal of Environmental Science. 4(2): 101-114.

[40] Ogbeibu, A.E. and Oribhabor (2002). Ecological impacts of river impoundments using benthic macro invertebrates as indicators. Water Research 36: 2427-2436.

[41] Tagliapietra, D. and Sigovini, M. (2010). Benthic fauna: collection and identification of macrobenthic invertebrates. Istituto di Scienze Marine, Consiglio Nazionale delleRicerche (CNR-ISMAR), Riva SetteMartiri 1364/a 30122, Venice, Italy.

[42] Zabbey, N. and Arimoro, F. O. (2017). Environmental forcing of intertidal benthic macrofauna of Bodo Creek, Nigeria: preliminary index to evaluate cleanup of Ogoniland. Reg Stud Mar Sci 16:89–97.

[43] Isaac, O. (2013). Effect of oil spill on macro-zoobenthos in Bodo creek, Nigeria. Unpublished (Undergraduate thesis), Department of Animal and environmental Biology, University of Port Harcourt, Nigeria.

[44] Nwipie, G. N., Hart, A. I., Zabbey, N., Sam, K., Prpich, G. and Kika, P. E. (2019). Recovery of infauna macrobenthic invertebrates in oil-polluted tropical soft-bottom tidal flats: 7 years post spill.

[45] Nkeeh, D. K. (2021). Impact of Oilspill Cleanup on Macrozzobenthos in Bodo Creek, Nigeria (PhD thesis), University of Port Harcourt, Rivers State,Nigeria.