Sustainable Remediation and Rehabilitation of Biodiversity and Habitats of Oil Spill Sites in the Niger Delta

Main Report including Recommendations for the Future

A report by the independent IUCN–Niger Delta Panel (IUCN–NDP) to the Shell Petroleum Development Company Ltd of Nigeria (SPDC) – July 2013

About IUCN

IUCN, International Union for Conservation of Nature, helps the world find pragmatic solutions to our most pressing environment and development challenges.

IUCN's work focuses on valuing and conserving nature, ensuring effective and equitable governance of its use, and deploying nature-based solutions to global challenges in climate, food and development. IUCN supports scientific research, manages field projects all over the world, and brings governments, NGOs, the UN and companies together to develop policy, laws and best practice.

IUCN is the world's oldest and largest global environmental organization, with more than 1,200 government and NGO Members and almost 11,000 volunteer experts in some 160 countries. IUCN's work is supported by over 1,000 staff in 45 offices and hundreds of partners in public, NGO and private sectors around the world.

www.iucn.org

Sustainable Remediation and Rehabilitation of Biodiversity and Habitats of Oil Spill Sites in the Niger Delta

Main Report including Recommendations for the Future

A report by the independent IUCN–Niger Delta Panel (IUCN–NDP) to the Shell Petroleum Development Company Ltd of Nigeria (SPDC) – July 2013

Published by: IUCN, Gland, Switzerland

Citation: IUCN Niger–Delta Panel (2013). *Sustainable remediation and rehabilitation of biodiversity and habitats of oil spill sites in the Niger Delta: Main report including recommendations for the future.* A report by the independent IUCN–Niger Delta Panel (IUCN–NDP) to the Shell Petroleum Development Company of Nigeria (SPDC). July 2013. Gland, Switzerland: IUCN. xxpp.

ISBN: 978-2-8317-1617-6

Cover photos: Image of the Niger Delta from space (courtesy of NASA), with community (first line (all by Alex Chindah) and main habitats overlain (second line from top left to right: lowland forest (Alex Chindah); freshwater (Alex Chindah); barrier islands (Friday Idogiye Amain); and mangroves (nigerdeltarising.org).

Layout by: Nigerian Environmental Study/Action Team

Produced by: IUCN–Niger Delta Panel

Available from: IUCN (International Union for Conservation of Nature)
Business and Biodiversity Programme (BBP)
Rue Mauverney 28
1196 Gland
Switzerland
Tel +41 22 999 0000
Fax +41 22 999 0002
biobiz@iucn.org
www.iucn.org/publications

CONTENTS

Annexes*

* The annexes are separate documents from this report and will be made available by request via email to biobiz@iucn.org.

Preface

This report presents the main findings and recommendations of the IUCN-Niger Delta Panel, regarding the sustainable remediation and rehabilitation of oil spill impacted sites in the Niger Delta. It has been prepared for the Shell Petroleum Development Company Ltd of Nigeria (SPDC) and represents the Panel’s first year of work. It therefore focuses on the first two of the four objectives set out for the Panel, namely to ‘develop and provide standards and best practice guidance on remediation and rehabilitation’ and ‘encourage uptake of the guidance by SPDC and others’. The overriding priority here is to provide advice for SPDC and make a start, as soon as possible, on the process of increasing effectiveness of ecosystem restoration in oil spill sites.

The report, which should be viewed as the Panel’s main reference document, may be updated periodically as new information becomes available. It sets out the Panel’s overall strategy for sustainable remediation and sets the scene for the other two objectives of the Panel’s work: to ‘develop a strategy to safeguard the Niger Delta’s remaining areas of biodiversity’ and ‘build capacity with local Nigerian organizations’. Now that the recommendations contained in this report have been proposed, SPDC can soon start on the planned set of field pilots, based on specific advice from the Panel and monitored by the Panel over the next two years.

A series of six annexes support this report. These are technical supporting documents that provide details on a variety of issues. Annex I comprises eight documents including four biophysical and four social and health assessment reports for the four sites visited. The social assessments deployed Rapid Rural Appraisal techniques (RRA) to give an indication of gaps that the Panel’s recommendations seek to bridge in order to prepare communities living in the neighbourhood of oil spill impacted sites to be engaged in remediation activities. The biophysical reports indicate pollution levels and response of biota and give an indication of remediation approaches and methodologies that would be most appropriate. Annex II outlines the overall environmental legislative framework that guides oil companies in Nigeria; Annex III is the Panel’s recommendations to guide more stringent levels for pollutants that should enable ecosystem recovery; Annex IV and V explain the application of remediation methodologies and protocols and the parameters for the field trials. Annex VI indicates the various consultations that have been held during the preparation of this report.

In addition to these six annexes, the Panel is already working on further guidance requested by SPDC to provide additional detailed information on in situ remediation of oil spill impacted sites. An Annex VII, under preparation, will include five reports that describe socio-environmental plans that cover relevant activities for improved integration of communities in remediation activities. Annex VIIa will cover socio-environmental plans for remediation approaches applicable to the soils and freshwaters of mangroves and creeks, while Annex VIIb will cover socio-environmental plans for the upper flood plains and freshwater ecosystems. Annexes VIIc, VIId and VIIe will cover biodiversity, a special report on the mangroves of Nembe and a recommendation for groundwater remediation in areas where communities rely solely on groundwater.

Glossary

Term	Definition
Baseline monitoring	Characterizing existing biota, chemical or physical conditions for planning or future comparisons.
Community ownership (of a process or project)	Communities participating or buying into a process/project such that they are part of the key decision–making process.
Community participation	Total involvement of a community in a project or process such that the community becomes a partner.
Condition assessment	An objective procedure to characterize the present state of a natural resource in an area and to diagnose resource impairment that can be remedied by restoration activities.
Control site	A study location nearly identical to the remediated location, with the exception that no remediation occurs. See also *reference site*.
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Article 2 of the Convention of Biological Diversity).
Ecosystem functions	The processes of production and dynamics of resources (organic matter, nutrients, biomass, elements) and energy through systems. A set of ecological processes responsible for providing an environmental good or service (Gilbert and Janssen, 1998).
Endangered (or threatened) species	Species in danger of extinction throughout all or a significant portion of their range.
Exit strategy	Arrangements that are put in place to ensure continuity and administration of a project after the provider/executor has left the scene.
Forest resources	Resources and values associated with forests and range including, among others, timber, water, wildlife, fisheries, recreation, botanical forest products, forage, and biological diversity.
Freedom to operate	Freedom to carry out activities (in a community) after permission has been granted by traditional and governmental authorities.
Global Memorandum of Understanding (GMOU)	An arrangement instituted amongst SPDC's host communities for the efficient and effective delivery of corporate social responsibility projects.
Habitat creation	Construction of a new habitat or ecosystem where it did not previously exist. This is often part of mitigation activities.
Habitat enhancement or improvement	Improvement of the quality of a habitat through direct manipulation. It does not necessarily seek to restore full functions or conditions to the pre-spill state. Some practitioners call this partial restoration.
Livelihoods	Economic activities that people engage in for their living.
Mitigation	Activities taken to offset the impairment of natural environments where restoration or rehabilitation is not feasible. Mitigation, as a last recourse, may not replace 'like with like' and may not be undertaken in the same area but may help protect species or stocks at risk.
Monitoring	Systematically checking or scrutinizing something for the purpose of collecting specific categories of data, especially on a recurring basis. In ecology, it generally refers to systematically sampling something in an effort to detect or evaluate a change or lack of change in a

	physical, chemical or biological parameter.
Reference site	Site in a relatively natural state, representative of conditions before oil spills.
Reclamation	Returning an area to its previous habitat type but not necessarily fully restoring all functions.
Rehabilitation	Restoring or improving some aspects of an ecosystem but not fully restoring all components. This is a general restoration term that can include habitat creation, improvement, enhancement or reclamation.
Remediation	The clean-up and recovery from an oil spill.
Restoration	Returning a habitat to its original undisturbed condition (e.g., the pre-spill state). In this report the term “restoration” is meant to include rehabilitation which in turn can include the creation, improvement, enhancement and reclamation of biodiversity and habitats.
Stakeholder	People and organizations that affect or are affected by projects.
Sustainable development	The type of development that improves the welfare of people at the present time without compromising that of future generations.
Traditional governance structure	Social organization and hierarchy of power and authority by which communities are governed, including traditional social control mechanisms.
Traditional knowledge	Indigenous/traditional knowledge based on long-standing traditions and practices of local communities.

Abbreviations

CBO	Community-based organization
CoSC	Chemical of Special Concern
DPR	Department of Petroleum Resources (Nigeria)
EC	European Commission
EGASPIN	Environmental Guidelines and Standards for the Petroleum Industry in Nigeria
GMoU	Global Memorandum of Understanding
HIIC	Honorary International Investors Council
IBAs	Important Bird Areas
IBAT	Integrated Biodiversity Assessment Tool
IOCs	International Oil Companies
IUCN	The International Union for Conservation of Nature
BBP	IUCN's Business and Biodiversity Programme
IUCN–NDP	IUCN–Niger Delta Panel
K_{oc}	Organic carbon content coefficient
NAPIMS	National Petroleum Investments and Management Services (Nigeria)
NDES	Niger Delta Environmental Survey
ND–HDR	Niger Delta Human Development Report
NEST	Nigerian Environment Study/Action Team
NGO	Non-governmental organization
NNPC	Nigerian National Petroleum Corporation
NOAA	National Oceanic and Atmospheric Administration (USA)
NRCRI	National Root Crops Research Institute (Nigeria)
OECD	Organisation for Economic Cooperation and Development
OPTS	Oil Producers Trade Section (Nigeria)
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
QA/QC	Quality Assurance and Quality Control

RENA	Remediation by Enhanced Natural Attenuation
RMS	Remediation Management Systems
SPDC	The Shell Petroleum Development Company of Nigeria Limited
TPH	Total Petroleum Hydrocarbon
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

Executive summary

The IUCN–Niger Delta Panel

The IUCN–Niger Delta Panel (IUCN–NDP) was established in January 2012 at the request of Shell Petroleum Development Company of Nigeria Limited (SPDC), to provide science-based recommendations for the remediation and rehabilitation of biodiversity and habitats of oil spill sites in the Niger Delta. The Panel was created with the involvement of IUCN Members in Nigeria, the IUCN Commissions and the IUCN Secretariat. The Panel comprises international and local experts in issues relating to oil spill recovery including hydrocarbon pollution, biodiversity conservation of terrestrial and aquatic ecosystems, restoration ecology and environmental sociology. It is managed by the IUCN Secretariat under its Business and Biodiversity Programme.

The Panel's work aligns with the IUCN Principles for Engagement with the Private Sector and with the IUCN Council recommendations on engagement with Shell, namely to:

- give greater priority and emphasis to biodiversity conservation and equity outcomes;
- draw on the expertise of IUCN to guide Shell on how to enhance its biodiversity conservation performance; and
- prevent biodiversity losses from Shell projects including in areas important for biodiversity outside protected areas.

The objectives of the IUCN-NDP are to:

- develop and provide standards and best practice guidance on remediation and rehabilitation;
- encourage uptake of the guidance by SPDC and others;
- develop a strategy to safeguard the Niger Delta's remaining areas of biodiversity; and
- build capacity with local Nigerian organizations.

The IUCN–NDP was tasked with proposing a set of recommendations within its first year of operation (i.e. by early 2013) for enhancing the approaches used to remediate and rehabilitate oil spill sites in the Niger Delta. Later in 2013 the Panel will begin monitoring the implementation of its recommendations by SPDC and in 2014 the Panel will assess the efficacy of its own recommendations and the efficiency of SPDC's implementation of these recommendations. At the end of this three-year period the Panel will make any necessary modifications to the recommendations and propose a further monitoring programme to be undertaken by a third party for a further seven years, to enable SPDC to gauge the success of the rehabilitation of biodiversity and livelihoods on these oil spill impacted sites.

The overall theme of the IUCN–NDP project in the Niger Delta is 'Sustainable Remediation and Rehabilitation'. This concept builds on IUCN's philosophy of best practice in the conservation of nature. The Panel has adopted this approach to drive its response to the many complex and interwoven challenges that the Niger Delta presents in the context of restoration of biodiversity and livelihoods.

Background to the recommendations

Oil activities by their very nature can have far-reaching environmental impacts and even more so in fragile and productive ecosystems like the Niger Delta. The Niger Delta has been under extreme stress for decades due to a combination of complex issues including environmental, socio-political, socio-cultural, and economic challenges—all exacerbated by continuing anthropogenic activities in direct relation to oil and other economic activities (including illegal artisanal crude oil refining, sabotage and oil theft).

Over decades, the environmental stress has increased and livelihoods have been impacted by a combination of these factors, as well as lingering residues of pollutants. This has not provided a conducive environment for the recovery and return of biodiversity. At the same time, worsening crises of poverty and unemployment have increased restiveness among the youth of the delta region.

The recommendations proposed by the IUCN–NDP in this report are aimed at addressing this very complex situation by understanding and tackling the underlying problems relating to remediation issues. The goal is to develop a robust approach to improving oil spill remediation and enhancing the environmental conditions that will support reappearance of biodiversity and subsequently ecosystem recovery. The recommendations focus on key gaps in procedure, remediation, conservation of biodiversity and socio-environmental strategy. Actions in all these areas are needed to ensure quicker action on oil spills, a deepening of remediation mechanisms, and revision of existing standards to boost the recovery of ecosystems, livelihoods and associated social values.

Whilst SPDC has implemented its remediation measures to meet the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) standards, IUCN–NDP recommends that new, tighter standards for ecosystem rehabilitation in the Niger Delta be developed, based on scientific calculations, field trials and existing best practice. Alongside this, and in order to ensure that any solutions are sustainable, there is need for a socio-environmental strategy to strengthen the involvement of community stakeholders in practical and meaningful ways.

The Panel recognizes that developing and maintaining a rapid spill response in the long term will require the involvement of other members of the oil industry as well as the Nigerian authorities. This broad-based, collaborative approach will be vital to ensure in-country capacity for an around-the-clock response with adequate equipment and resources.

IUCN–NDP consultations

The IUCN–NDP commenced its work in April 2012, with internal consultations amongst members, experts and organizations who had carried out studies in the Niger Delta (e.g. the Niger Delta Environmental Survey (NDES) and the United Nations Environmental Programme (UNEP)).

Subsequently, the Panel commenced consultations with a broad cross-section of stakeholders including SPDC, government, civil society, NGOs and communities within selected areas impacted by oil spills (see Annex VI). In September 2012, the IUCN–Niger Delta Panel's work was presented to the international community under the platform of IUCN's World Conservation Congress in Jeju, South Korea. The Panel's broad strategy was well received by the international community who observed that the overall approach was realistic. In Nigeria, the government and community stakeholders also welcomed the approach and especially endorsed the Panel's concept to integrate communities into the remediation processes. Training and capacity building on remediation activities will be provided in communities through their community based organizations to enable them to implement remediation and rehabilitation processes as well as other viable income-generating opportunities with a provision for an exit strategy for SPDC as initiator and sponsor.

Site selection and field visits

Following inauguration, the Panel visited community stakeholders over a three-month period and conducted biophysical, social and public health field work to deepen its understanding of the biodiversity status and the roles and responsibilities of different stakeholders, in order to be able to offer credible advice.

The Panel had earlier selected four sites, based largely on the ecological zones of the Niger Delta. These zones are recognized by delineation of soil types as influenced by hydrological dynamics, tides, and fluvial processes of the River Niger as well as wave action of the Atlantic Ocean on the shoreline morphology (Abam, 2001; Stutz and Pilkey, 2002). Using a map supplied by SPDC for oil spill sites in the Niger Delta (covering the period from about 1994 to 2010), the Panel selected Yokri, a barrier Island in Delta State, Kolo Creek a freshwater ecosystem in Bayelsa State, Oguta, a lowland forest in Imo State and Soku, a mangrove ecosystem in Rivers State.

In selecting these study sites, other considerations were also taken into account, including the length of time since the spill occurred and the accessibility and security of the sites. The issue of security was a very serious consideration due to the ongoing kidnappings and threats posed by a number of militant groups operating in the region. These security threats have persisted through to the release of this report and such are the threats that the Panel's site investigations were delayed a number of times. It is also noteworthy that the Panel was unable to visit Yokri due to significant flooding that cut the only access road from Bayelsa to Delta State. The flooding and the unfavourable security in this area led the Panel to select an alternative study site—Nembe—another mangrove ecosystem that also presented significant ecological issues and that was a key operational area for SPDC. It is worth noting that the Panel was accompanied by the heavily armed Joint Task Force of the Nigerian Security forces for the Nembe field trip. This illustrates the challenging conditions for field visits within which the Panel is operating.

One of the critical outcomes of the field investigations was that community stakeholders were eager to be part of remediation activities and felt it was unacceptable that they were excluded from decisions with such far-reaching impacts on their environment and communities. This was a common position expressed very clearly from the three sites visited in Oguta, Soku and Imiringi, near Kolo Creek flow station (near Oloibiri, Nigeria's first oil well drilled in 1956).

Regarding the widespread reduction in ecosystem productivity seen in the Niger Delta, the Panel noted that other anthropogenic factors, such as sabotage, crude oil theft, artisanal refining, security issues and blocking of access to sites, in addition to operational spills and occasional infrastructure failures, were also contributors to degradation of the environment.

From interactions with the government and regulatory stakeholders it was found that these parties were very interested in the prospect of the Panel's work changing the direction of remediation activities and achieving a positive impact.

Regarding challenges to remediation, it was observed in the Kolo Creek biophysical analysis that residues of chemicals of special concern (CoSC) such as nickel and chromium were above regulatory standards, in spite of the natural biological degradation that had been occurring and the significant flooding during the time of the field investigations. Although the source of nickel and chromium was not established, the levels of polycyclic aromatic hydrocarbons (PAHs) obtained from samples taken during the Panel visits were within the EGASPIN standards of 2002 see Annexes Ia and III).

The Panel also observed that stricter monitoring of contractors is required during and after remediation, to ensure that the activities they have implemented are in accordance with regulatory standards. The Panel observed for example, that in a recently concluded remediation site in Soku, the hydrocarbon levels were higher than the EGASPIN standards of 2002, even though all the authorities had signed off on the certificate for a clean bill of health for that site.

In Oguta, the Panel could not implement a biophysical study of soil and sediments owing to the flood disaster in October 2012 that submerged the sites to depths of over 10 feet. Though the total hydrocarbon concentration recorded for the surface waters was high, the Panel noted that this may have been aggravated by an influx of hydrocarbons during the flooding, so this has not been compared with EGASPIN standards or other sites in the report.

With respect to EGASPIN standards in general, the Panel noted that the target limits for CoSC were higher than the limits set in other countries such as USA, Canada and the Netherlands (see Annex III). Some PAHs that are considered carcinogenic by the United States Environmental Protection Agency (USEPA) and are commonly found in aged or weathered oil spills are not listed at all in EGASPIN. For example, benzo(a)pyrene, which EPA and the World Health Organization (WHO) consider to be one of the most toxic and carcinogenic PAHs, has no listed target levels for soil and surface water in EGASPIN. Furthermore, EGASPIN levels are generalized and not site-specific to the four ecozones. In contrast, Canadian and American target levels are either site-specific or soil-specific. There is a need to encourage a review of some levels by the regulatory agency in order to promote quicker ecosystem recovery. In the meantime, SPDC is encouraged to use the suggested target levels indicated in Annex III as a guide for monitoring ecosystem recovery, until specific standards are established for the Niger Delta ecosystem. Currently there are no reliable references or data to indicate sensitivity of organisms to hydrocarbon pollution in the Niger Delta. This is a gap the Panel needs to bridge in order to track tolerance levels for organisms during the field pilots that will be implemented by SPDC. Such tracking will enable the Panel to determine the values at which organisms begin to respond positively to the remediated environment.

Mainstreaming biodiversity conservation is imperative in the Niger Delta. This should be a major concern for all international oil companies (IOCs), especially as the operational sites of different IOCs exist in close proximity of each other, hence the recommendation for wider collaboration and transparency amongst oil companies and the government. An effective platform to implement this new direction needs to be established, and the Oil Producers Trade Section (OPTS) could be an effective catalyst because all the major oil companies are members of this organization. The Panel is currently reviewing modalities through which this process may be effectively applied in collaboration with IUCN.

Independent laboratory analyses

In order to determine the environmental conditions of the study locations and provide an evidence base for the recommendations, samples were taken during the field visits. These samples, comprising soil, surface water, groundwater, sediment and biota, were analysed at independent laboratories. For effective Quality Assurance and Quality Control (QA/QC), sample analyses were carried out in two separate laboratories (Institute of Pollution Studies in Rivers State University of Science and Technology and Rofnel Energy Services Ltd, Port Harcourt).

Conclusions

Based on the observations by the Panel, the current remediation practices in oil-impacted areas in the Niger Delta do not visibly support the needs of biodiversity rehabilitation. This is due to inadequate benchmarks for target values of pollutants' residues in the environment and the fact that regulators, oil companies and communities have not taken concerted action to implement oil spill responses and remediation in a timely manner. The methods and regulatory standards for biodiversity and habitat rehabilitation have also not been adequately established.

The Panel is optimistic that in the long term, proper implementation of these recommendations will contribute to improved environmental management of the Niger Delta. Taken as a whole, the recommendations should improve the current situation in the short term whilst ensuring sustainability of restoration of biodiversity and habitats of the Niger Delta in the longer term.

Given the experiences of the Panel, it is clear that addressing the biodiversity and habitat remediation issues must become a top priority. The Panel recognizes that shouldering the burden of doing this extends beyond SPDC and some of the recommendations such as monitoring of biodiversity with modern technology are better served by a separate organization. There is therefore a need to develop a wider strategy and involve other members of the oil industry as well as Nigerian authorities and communities to jointly explore these challenges and consider the need for such an organization. The IUCN–NDP pledges to support this initiative by working through the Federal Ministry of Environment (an IUCN Member), the Department of Petroleum Resources (DPR) and the

National Petroleum Investments and Management Services (NAPIMS) to motivate other stakeholders in the oil industry and other relevant bodies to address this issue proactively.

The Panel also recognizes that repeated spills from anthropogenic activities—especially crude oil theft and illegal refining—are at critical levels, causing significant economic and environmental impacts. This has led to Nigeria's Honorary International Investors Council (HIIC) urging the government to act fast to curb these activities (This Day Newspapers March, 6th 2013). Repeat spills from these sources are difficult to plan for but it is hoped that the measures the Nigerian government has put in place to work with the youths of the Niger Delta will yield benefits in this regard. Furthermore the socio-environmental strategy may yield benefits that will urge a re-think on these illegal operations.

Recommendations

This document contains the IUCN–NDP recommendations for the sustainable remediation and rehabilitation of biodiversity and habitats of oil spill sites in the Niger Delta. Background information, including protocols and references to proven scientific methods, is also provided. The recommendations, set out in Chapter 4, cover the following five areas, which were considered by the Panel to be the most critical:

i. Redefinition of some SPDC internal environmental management procedures to broaden intervention mechanisms;
ii. Revision of oil spill response procedures to enhance rapid response to new spills;
iii. Evolution of new, but proven, scientific approaches to boost and support in situ biological remediation and rehabilitation processes;
iv. Supporting the sustainability of remediation at the community level by the evolution of a socio-environmental strategy; and
v. Evolution of a Niger Delta biodiversity best practices strategy that seeks to establish institutional support for broader engagement of communities, the oil industry and government in the conservation of biodiversity of the Niger Delta.

The Panel's main recommendations are as follows:

SPDC internal environmental management procedures:

- Redefine receptors used in the business model (SPDC's Remediation Management System-RMS-version 3- 2011) to include a better representation of key Niger Delta biodiversity and associated social values;
- Redefine monitoring protocols, such as the introduction of independent monitoring teams to undertake scheduled visits and the use of checklists on target standards and biodiversity rehabilitation indicators;
- Review and revise the assessment feedback cycle to refine company actions on a rolling basis; and
- Improve ready access to information, such that it is quicker and easier to obtain relevant information for internal assessments and analyses of situations.

Oil spill response procedures:

- Speed up response to oil spill incidents;
- Redefine the nature of treatment of new and aged oil spill sites bringing it up to international and industry-based standards that support quicker ecosystem recovery;
- Expand remediation mechanisms to include restoration and rehabilitation actions;
- Introduce procedures to redefine and reinforce best practices for the SPDC remediation team; and
- Identify key sensitive and pristine areas that would need special protection in the event of their being threatened by oil spills.

Remediation and rehabilitation procedures:

- Expand the range and improve the efficiency and effectiveness of remediation actions targeting major habitat types, drawing on the best available scientific information and experience;
- Redefine and establish intervention and target standards to support remediation and rehabilitation respectively;
- Include biodiversity rehabilitation techniques along with remediation actions through trials on the major habitat types in the Niger Delta; and
- Strengthen existing sign-off procedures by introducing an annual monitoring of ecosystem recovery within three years post-remediation before internal sign-off. This will only apply to areas where recontamination has not occurred, to ensure that residues of Chemicals of Special Concern (CoSC) have reduced to the required levels and to ensure that there is clear evidence of restoration of biodiversity and ecosystem function in line with the Outcome Success Matrix.

Socio-environmental strategy:

- Develop a socio-environmental plan that engages with traditional governance structures of neighbouring communities for the implementation of remediation and rehabilitation activities; although there is some evidence that SPDC is already doing so, there is room for improvement in the manner of interfacing with the various community groups;
- Create opportunities for community–based organizations (CBOs), non-governmental organizations (NGOs) and other organizations to participate in various aspects of the implementation of remediation and rehabilitation activities;
- Provide adequate information on bioremediation processes to communities and build their capacity to support new protocols for remediation and rehabilitation activities;
- Enhance and utilize the inherent capacities of Niger Delta communities such as labour and traditional knowledge, for sustainable remediation and rehabilitation activities;
- During implementation ensure that the communities have been adequately brought into the rehabilitation process and that SPDC can withdraw through a clearly defined exit strategy; and

- Where feasible make the bioremediation approach holistic by incorporating global Memorandum of Understanding (GMOU) arrangements for effective community participation.

The socio-environmental strategy is an approach to strengthen the capacity of communities to engage in recommended remediation activities to be implemented by SPDC, with additional benefits of providing sustainable income-generating activities either directly from remediation activities in their neighbourhoods or through related environmental projects.

Wider Niger Delta biodiversity best practices strategy

As described earlier, the immediacy of problems in the Niger Delta requires a focussed, step-wise approach to implementing the Terms of Reference for the Panel's work. The two remaining key objectives of the Panel are to develop a strategy to safeguard the Niger Delta's remaining areas of biodiversity, and build capacity with local Nigerian organizations. Biodiversity in the Niger Delta is facing tremendous threats to habitats due to anthropogenic factors such as pollution, urbanization, demands for better roads and waterways as well as deepening poverty of the region's growing population. In order to conserve habitats successfully, these threats need to be addressed from a much larger platform than the SPDC alone, and in a way that makes resources and methodologies accessible to all the stakeholder groups who need such assistance. This will require the involvement of government authorities, the wider oil industry, communities and NGOs in order to jointly address issues of major concern including:

- Regular reviews and updating of contingency planning and sensitivity mapping, including identification of the Delta-wide biodiversity hotspots and pristine areas;
- Providing capacity building, material support and other resources to promote remediation; and
- Maintaining best practice protocols, e.g. for the attainment of CoSC target levels and protocols for remediation and conservation.

Chapter 1

Background and role of the IUCN–Niger Delta Panel

The IUCN–NDP was formed as a result of an approach by the Shell Petroleum Development Company of Nigeria Limited (SPDC), on behalf of the NNPC/Total E&P/NAOC/SPDC Joint Venture, to IUCN in January 2011 through the existing Shell International/IUCN partnership arrangements administered between Shell International B.V. and IUCN's Business and Biodiversity Programme (BBP). The IUCN–NDP is facilitated by IUCN through the Nigerian Environment Study/Action Team (NEST), an IUCN Member in Nigeria.

The Panel is independent in its deliberations and advice, and comprises a seven-member group of technical experts in the science of oil spill management and oiled site remediation and rehabilitation. The Panel has been established to examine the ecological and socio-environmental aspects of current SPDC protocols and procedures in oil spill site remediation and to provide recommendations for improvements.

The main stakeholders for the IUCN–Niger Delta Panel work are SPDC Joint Venture (55% owned by the Nigerian government, also an IUCN Member), communities, Nigerian regulators, NGOs, IUCN Nigerian Members and other oil companies.

This project aligns with the IUCN Principles for Engagement with the Private Sector and with the IUCN Council's recommendations on engagement with Shell, namely to:

- give greater priority and emphasis to biodiversity conservation and equity outcomes;
- draw on the expertise of IUCN to guide Shell on how to enhance its biodiversity conservation performance; and
- prevent biodiversity losses in areas important for biodiversity outside protected areas.

1.1 Purpose and objectives

The purpose of the IUCN–NDP is to fulfil the wish of stakeholders and especially the Nigerian government, host communities and SPDC as well as other oil companies to improve upon remediation activities and find a sustainable and peaceful approach towards rehabilitation of biodiversity in habitats affected by oil spills. Specifically, the objectives of the Panel's work are to:

- develop and provide standards and good practice guidance on remediation and rehabilitation;
- encourage uptake of the guidance by SPDC and others;
- develop a strategy to safeguard the Niger Delta's remaining areas of biodiversity; and
- build capacity within local Nigerian organizations.

The work and findings of this Panel mark a new beginning towards developing a framework for a holistic approach that seeks to integrate all stakeholders in a practical and sustainable manner.
The rehabilitation and recovery of biodiversity and ecosystems seen so far in the Niger Delta is not sufficient, and this is partly due to inadequate benchmarks for pollutant levels in the environment. (See Annex III, Section iii). In addition, spill containment and clean-up are not implemented rapidly and the methods and regulatory standards for habitat rehabilitation need to be improved upon to support ecosystem recovery.

The Niger Delta needs more stringent target levels for recalcitrant hydrocarbons, based on the soil types of various ecozones and taking into account levels that will affect sensitive biodiversity and human health. The Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) need to be expanded to define more pollutant levels, including many of the toxic PAH target values for soil, surface and groundwater, as well as values reflecting impact from downstream activities including illegal refining of crude oil. Comparisons between EGASPIN's soil, surface and groundwater standards and those of Canada, South Africa, the UK, the Netherlands and some states in the USA, show that most of these countries' standards have set lower target values and are more stringent and site-specific. Some countries, such as South Africa and the UK, also do not have PAH levels for soil or surface water. EGASPIN policy is to adopt the most stringent values available at the time of comparisons with other countries (EGASPIN 2002). The Department of Petroleum Resources has scheduled a review of EGASPIN standards since 2010, though this has not yet been concluded (DPR, 2010). This has put many of its standards out of sync with other countries that undertook reviews in 2010 and 2012. There are also areas where EGASPIN values are stricter than other standards, e.g. for mineral oil (C15-C40), where the soil target and intervention values given by EGASPIN were found to be stricter than the corresponding values in the Dutch and American guidelines. Also, where given, Nigeria's mineral target values for soil are much lower (i.e. stricter) than the industrial/commercial soil target values for the UK, USA and South Africa. For polycyclic aromatic hydrocarbons in groundwater, the intervention values set in the EGASPIN and Dutch guidelines (where they are listed) are largely similar. However, in comparing their target values, the Dutch values are much lower (stricter).

Attaining best practice for reducing pollutant levels in the Niger Delta environment is very important and should be reflected in sign-off target values. The current EGASPIN target levels should be more specific to the different sites in the Niger Delta. For example, the very fine silty/clayey sediments of Soku cannot be compared to the more coarse sandy soils of Bonny area. Bonny and most of the coastal areas have sandy coarse soils due to influences of the sea, while some parts of the Niger Delta such as Nembe have clayey/silty soils due to influences of mangrove forests where the hydrology is the single most important factor in restoration design. Owing to increasing anthropogenic activities there is a need for site specificity, as indicated in the CoSC levels set in the standards for Alberta, Canada, and some states in USA, which show total petroleum hydrocarbon (TPH) values for specific soil types and locations (see Annex III for comparison of international standards and EGASPIN). The last EGASPIN review was conducted in 2002 and so with increasing levels of pollution in Nigeria, it is indeed time for another update of EGASPIN standards. The Panel would also recommend bio-indicators to track response to pollution in the environment as remediation progresses. This tool is essential to indicate the contaminant levels that organisms can tolerate without bio-accumulating toxicants in their tissues or showing other adverse responses. As conditions improve the bio-indicators should also show positive response to decreasing toxicity in their environments. This aspect of the recommendation has not been fully developed in this report as it will need to be investigated further in the field trials.

Given the problems associated with oil pollution in the Niger Delta and the institutional, social, economic and environmental consequences that occur when things go wrong, there needs to be a new collaborative, industry-wide approach to tackle these issues with the same priority as the oil industry handles health and safety issues.

Therefore the Panel's long-term vision envisages the government, oil companies and communities working together to dramatically reduce spill frequency and volume and improve remediation. This would see a new context for oil operations in the Niger Delta, with:

- a rapid and effective on-the-ground response to oil spills to contain, address and mitigate impacts on biodiversity and ecosystems; and
- ecosystem rehabilitation based on the best standards in the world.

The proposed steps towards achieving this vision are contained within the recommendations of the Panel.

1.2 Mode of operation

The Panel operates in an independent way and demonstrates transparency in how it carries out its work. The Panel maintains its independence to avoid conflicts of interest and is charged with providing advice irrespective of the causes or costs of spills. While it takes into account the knowledge and experiences of different stakeholders as they relate to oil spills and their remediation and rehabilitation, the Panel forms its own views on best practices, monitoring and the strategy to safeguard remaining areas of important biodiversity.

The Panel is made up of international and local experts and has made use of in-country working groups and task forces to help with the collection of data and the examination of relevant issues. While SPDC helped with the provision of its own internal data, the Panel also consulted other studies and environmental reports and articles from sources in Nigeria and from around the world. SPDC is expected to implement applicable recommendations, while the Panel will monitor and assess the effectiveness of SPDC's implementation during a three-year period and provide recommendations for longer-term monitoring and assessment by an independent body for a further seven-year period.

1.3 Activities

The overall goal of the Panel is to contribute to the remediation and rehabilitation of biodiversity and habitats following oil spills in the Niger Delta, and to develop protocols that would ensure no residual long-term adverse impacts to the affected ecosystems.

The specific activities which the Panel will undertake to achieve this goal include:

- Developing a set of standards and best practice guidance for SPDC’s implementation of remediation and rehabilitation practices based on best scientific and practical approaches.
- Working with the Nigerian regulator(s) to ensure that the proposed standards will improve upon existing standards by building on and complementing current standards applicable under Nigerian legislation and aligning with any future work.
- Developing appropriate monitoring and biodiversity impact and recovery indicators applicable to defined ecosystem types encountered within SPDC’s operational areas, which will be assessed for up to seven years. Such monitoring will be overseen by the Panel for the duration the Panel’s existence, and thereafter continued by SPDC.
- Providing, after a period of three years, an assessment of SPDC’s implementation, in terms of the health and recovery rates of the relevant ecosystems.
- Developing a strategy to safeguard remaining areas of biodiversity importance from effects of potential future spills.

In the pursuit of its goal, objectives and activities, the Panel is being guided by the annual work plan set out by the Chair, with contributions and agreement of the Panel, and approved by the IUCN Director General or delegated authority.

1.4 Challenges

The IUCN–NDP is undertaking this work at a time when perceptions about Niger Delta projects are pessimistic. This means that the Panel must seek to understand the roles that other Niger Delta projects have played and why the desired impacts may not have been achieved to date.

The Panel has strived to ensure that its recommendations are scientific, practical and sustainable because the expectations of stakeholders are extremely high and cut across a wide range of environmental, socio-economic, political and cultural issues. However, the Panel’s work in the field has been severely hampered by security issues in the Niger Delta, which have adversely affected the ability of the Panel to visit sites as frequently as would have been desired. Notwithstanding, the Panel has taken the tense security situation in its stride to ensure that information gathered from field observations, biophysical and social/health assessments as well as the extensive literature reviews were robust enough to support its recommendations. The Panel does have the advantage of coming at a time when several related studies have been undertaken and consequently there is adequate background information to provide a robust analysis of gaps. However, the Panel will need to be transparent about milestones and progress to enable stakeholders to understand what the Panel is doing and how its work is progressing. The fact that the recommendations will be implemented in the field by SPDC under the guidance and advice of the Panel means that success can be assessed quickly.

Chapter 2

Principles underlying remediation and rehabilitation of biodiversity and habitats in the Niger Delta

2.1 Background

The Niger Delta represents a closely woven, long-standing relationship between people and the environment. The delta is the drainage basin of the Rivers Niger and Benue and their numerous tributaries, which deposit rich alluvial soil thus creating a 30,000 km^2 wetland of global significance. The River Niger drains a large part of West Africa, discharging its waters and sediment, including exotic biota, into the Niger Delta (Abam, 2001). This supports the rich biodiversity of the delta, which has spawned a variety of food and material resources (Blench and Dendo, 2007) that have sustained ecosystem balance as well as traditional and sustainable means of livelihoods for centuries (World Bank, 1995).

The rich biodiversity of the Niger Delta is under threat from natural factors such as erosion and rising sea levels, as well as myriad anthropogenic factors, including oil and gas mining activities, unsustainable deforestation practices, upstream dams and urbanization. This, one of the most sensitive biodiversity hotspots in Africa has lost a large portion of its protected areas in the last five decades as result of these pressures. (Federal Government of Nigeria, 1999; Niger Delta Human Development Report, 2006; Phil-Eze and Okoro, 2009). The UNDP Human Development Report for the Niger Delta (2006) reports that the environment has been deteriorating at an alarming rate, creating deepening and pervasive poverty despite vast oil resources that account for over 95% of foreign revenue and over 40% of GDP in Nigeria. A number oil pollution impact assessment studies suggest that the high levels of pollution in the Niger Delta, particularly from residual/recalcitrant hydrocarbons, synthetic pollutants and continuing pollution from natural and anthropogenic activities means that habitats, livelihoods and people are now severely impacted (UNEP, 2011; Emoyan et al., 2008; Niger Delta HDR, 2006; World Bank, 1995). In pursuing sustainable solutions to the current pollution problems, the future strategy for addressing remediation and rehabilitation needs to take a more holistic approach, to better reflect the interdependencies between the people, environment and biodiversity of the Niger Delta (UNDP Niger Delta HDR, 2006).

This chapter briefly explores the key principles and issues that lie at the centre of such a sustainable approach. This context provides insight into the thinking of the Panel in developing its recommendations, namely why the recommendations are structured as they are and why they focus on remediation and rehabilitation while also addressing underlying ecosystem, economic and social issues. In essence, this is as much about providing the conditions for ecosystem recovery after oil spill as it is for sustaining livelihoods. It is also about considering the interests and concerns of stakeholders at all levels, not just in assessing and reacting to problems, but in delivering effective, efficient and sustainable solutions.

2.2 Delivering sustainable solutions

At the 1992 Earth Summit in Rio de Janeiro, it was recognized that the traditional sectoral approach to natural resource and environmental management was insufficiently addressing human impacts on the environment. The need for a holistic 'Ecosystem Approach' started to appear in initiatives and agreements. The idea of implementing such a holistic approach to environmental issues in the Niger Delta is nothing new, although up to now it has not been applied effectively.

The Niger Delta Human Development Report (ND-HDR, 2006) shows that unprecedented restiveness in the Niger Delta sometimes erupts into violence due to deep-rooted mistrust and frustration among poverty stricken communities suffering from administrative neglect, crumbling social infrastructure, high unemployment, and deepening poverty in a region that is blessed with vast oil and gas deposits, good agricultural productivity, extensive forests, excellent fisheries and a large labour force. The ND-HDR recommended promoting social inclusion of deprived and impoverished communities in development planning and mainstreaming of environmental sustainability, complemented by steps to conserve natural resources, reduce pollution and set adequate targets for clean air, water and soil, backed by vigorous enforcement of environmental standards and laws.

The Ecosystem Approach is now seen as key in delivering sustainable development, recognizing in its simplest form ecological, economic and social considerations and accepting that humans form part of ecosystems. Embodying such an approach in these recommendations merely reflects good practice and pre-existing and clear commitments for implementing the Ecosystem Approach stemming from the World Summit on Sustainable Development (Johannesburg 2002) and the Convention on Biological Diversity (Article 2 and Decision V/6).

Considering the vast area impacted by pollution, the complexity of pollutants (including mixtures of synthetic/residual and recalcitrant hydrocarbons), the close proximity of communities to oil spill sites and existing sensitivities within the region, new approaches and recommendations must consider practical, safe, cost-effective, low-technology and efficacious methods to achieve the desired results within reasonable timeframes.

The application of remediation techniques has advanced enormously over the last decade and provides a host of options.

2.3 Community integration in sustainable remediation

This section explains the need to appreciate the linkages between environmental degradation, biodiversity loss and poverty. The Panel has noted that consistent exclusion of communities of the Niger Delta from oil spill remediation, restoration and rehabilitation activities has led to denial of associated income-generating opportunities for these communities. The remediation approach suggested by the Panel seeks to remedy this situation by integrating communities into the process, so they can take advantage of these types of opportunities. This would potentially provide an incentive for them to support anti-sabotage and anti-oil theft activities and engage in biodiversity conservation. This would most likely lead to a significant reduction of Tier 1 spills and a lessening of biodiversity threats over time.

The Panel found that current capacities within communities cannot sustain the proposed remediation strategy unless capacity building and income generation are seriously addressed. Stakeholder consultations with government and communities (see Annex VI) strongly endorsed the integration of communities in the remediation processes of SPDC in order to achieve the aforementioned objectives. Furthermore, from its interactions with communities, the Panel has sought to determine the best approaches to build the capacity of community groups to ensure effective and profitable participation in remediation.

The Panel also considered that in the future, when biodiversity conservation approaches are more fully developed, communities would play a key role in this too. To this end, there is a need to develop a capacity-building framework for this and other related community activities. Such a framework would need to take into account the challenges to biodiversity conservation in the Niger Delta, including urbanization, deepening poverty and declining incomes (which exacerbate the dependence on biodiversity as food and income resources) as well as habitat loss from pollution and dredging (ND-HDR 2006; Blench and Dendo, 2007 citing Powell, 1995; IUCN–NDP, 2012).

During the field visits, the Panel did not observe many community-level commercial activities that would be substantial enough to offset the loss of income due to pollution and other factors (ND-HDR 2006, FGN 2009, Powell, 1995, IUCN–NDP 2012). At Imiringi, for example, the Panel observed that the farmers and fishermen who had lived quite comfortably off the proceeds from their plantain plantations and abundant fisheries were finding it difficult to switch occupation, having experienced a severe decline in their incomes over the last two decades. While the biophysical report did not conclusively indicate hydrocarbon pollution, the results did show residues of hydrocarbon contamination from spills that had occurred over fifteen years prior were still slightly above the EGASPIN target levels. The water samples also showed very low abundance and diversity of phytoplankton, zooplankton and periphyton and extremely small numbers of only one fish species. Where the primary levels of the lower food chain is so poor, fish productivity will also be low. Clearly, there are signs of environmental stress, but the Panel’s Terms of Reference and other operational constraints at the time of the field visits did not allow for a more in-depth investigation. However, there is an abundance of scientific information for similar work all over the Niger Delta, which the Panel is referencing in order to develop its recommendations.

Interestingly, Agbogidi and Ufuoku (2006) have explored income generating opportunities associated with biodiversity conservation, which would strengthen the Panel’s future recommendations on this issue (see Annex VIIc).

2.4 Key issues

A future sustainable bioremediation strategy for the Niger Delta would need to take account of the following key factors:

Environmental

- Oil spill containment and clean-ups should occur rapidly after spill incidents to limit the spread and depth of subsequent pollution.
- Work with natural processes; the biological processes of micro and macro organisms as well as natural chemical and physical processes will ultimately degrade pollutants naturally; working with these processes is a cost-effective and efficacious in situ treatment for large-scale remediation in the ecologically sensitive Niger Delta environment.
- In addition to the bioaugmentation achieved with 'remediation by enhanced natural attenuation' (RENA), there is a need to employ biostimulation to speed up biodegradation. Biostimulation is safe as it applies the same basic principles of stimulating growth as are used in agriculture.
- Employ a combination of technologies using various remediation techniques, including land farming/bioremediation, rhizoremediation technology, phytoremediation, phycoremediation, and the application of biosurfactants (see Chapter 3 for a description of these techniques).
- Understand that mangroves, as fragile and sensitive ecosystems, require hydrological restoration to be undertaken immediately after seismic or pipeline installation activities.
- Recognize that mangrove ecosystems are a major carbon sink owing to their capacity to sequester and store carbon, and therefore their protection and rehabilitation will support climate change mitigation, as well as biodiversity conservation.

Economic

- Recognize the interests of other stakeholders in addressing the environmental issues of the Niger Delta, as a means of tackling unemployment, poverty and restiveness in the region.
- Recognize the potential for employment and income generating opportunities in sustainable bioremediation, as large-scale bioremediation requires a large labour force.
- Recognize the economic impacts of rains, floods and tides in spreading and transferring pollutants, thus prolonging adverse impacts and costs on biodiversity and livelihoods.
- Recognize that investments in scaling-up remediation and rehabilitation of biodiversity and habitats will facilitate improvement of livelihoods in the long term.
- Recognize the multiple values of mangrove ecosystems with regard to protection of shorelines and water bodies, provision of wood products and as fishery habitats and therefore promoting the conservation and rehabilitation of mangroves will enhance fisheries and livelihoods.
- Recognize that the application of biological agents has economic potential, such as the production of biological dispersants.

Social

- Recognize that the Niger Delta has a relatively young population and that the rate of unemployment is high, so activities leading to employment opportunities are welcome.
- Recognize that to accelerate the remediation process, cost-effective solutions will involve community consultation and engagement.

- Recognize the need to ensure that the processes of remediation and rehabilitation take into account the needs and concerns of local communities help improve livelihoods impacted by pollution.
- Recognize that SPDC has global Memoranda of Understanding (GMOUs) to establish and maintain Trust Funds in communities.
- Recognize the need for a comprehensive socio-environmental programme that encourages active community engagement in remediation and rehabilitation activities.

Chapter 3

Background to recommendations for remediation techniques in the Niger Delta

3.1 Introduction

This chapter provides the essential context for the Panel's recommendations for bioremediation in the Niger Delta. It describes the range of bioremediation options available and comments on the challenges to implementing bioremediation from a number of perspectives. It also discusses broader challenges to remediation of oil spills in the area. These include the scale of the area and anthropogenic influences, such as sabotage, crude oil theft, illegal refining, infrastructure failures, and some of SPDC's internal environmental management processes and policy issues.

In the Panel's view, the methodologies currently being used for the remediation and rehabilitation of oil spill-impacted sites in the Niger Delta do not fully address the need for rehabilitation of biodiversity. In one particular case, the methods used do not meet Nigerian standards or international industry best practices (see Annex Ic). In assessing remediation and rehabilitation approaches, the overriding consideration is the need to apply the safest, most efficacious, cost-effective and sustainable approach that will improve the situation and bring about measurable changes in the shortest possible timeframe. Recent advances in ecosystem restoration elsewhere have shown that enhanced biological remediation by stimulating and accelerating naturally occurring processes has the potential to significantly improve the recovery of ecosystems impacted by oil pollution in the Niger Delta (USEPA, 2004).

This chapter takes into account current remediation technologies, the concerns, observations and perceptions of stakeholders that emerged during discussions in the course of recent field visits to Kolo Creek, Soku and Oguta pilot areas, as well as discussions with SPDC staff.

3.2 Types of bioremediation

The Panel reviewed different bioremediation options that could be appropriate for the Niger Delta, based on their feasibility under local conditions. These are outlined below.

3.2.1 Land farming

This process involves biostimulation of microbes to increase biological activity using nutrients (nitrogen, phosphorus, potassium), tilling or air sparging for better aeration or oxygenation. Hydrogen peroxide is a cost-effective means of aeration that can deliver 50mg/l of oxygen (compared to aeration using atmospheric oxygen, which delivers about 9mg/l of oxygen). Hydrogen peroxide has been successfully and extensively used by the United States Environmental Protection Agency (USEPA) since 1997 in several pilot and full-scale initiatives on remediation of groundwater. (USEPA, 2004) However, when used for bioremediation or gardening (for pest control), hydrogen peroxide should be in dilute form of between about 3% and 10% (depending on the manufacturer's guide for the specific application) and should be used in a specified ratio with iron, nitrogen and potassium, based on indicative soil tests or trials. Some dried plant products, such as sphagnum peat moss, potato peels and kenaf, can greatly increase the effectiveness of land farming techniques, when applied appropriately to the in situ conditions. Sphagnum peat moss has a special ability to 'wick' or attract oil on water to itself and can absorb ten times its cell capacity. It also has humic acid incorporated within its cells to catalyse intra-cellular degradation. The most challenging aspect of land farming is oxygenation because anaerobic conditions can occur frequently during land farming, stifling aerobic activity. Even though some microbes are able to switch modes from aerobic to anaerobic, the latter is not as efficient in degradation as the former. Aeration of large areas is logistically difficult and the prolonged application of fertilizers may have negative effects as residues increase and are not utilized or degraded effectively. The success rate of land farming varies widely depending on a variety of physico-chemical and anthropogenic factors. The physico-chemical challenges can be solved by increasing the bioavailability of the substrates, especially the recalcitrant and residual hydrocarbons, speeding up degradation activity of indigenous bacteria and fungi and using organic materials to enhance degradation (Abu and Atu, 2008).

3.2.2 Hydrogen peroxide treatment

In addition to its use in oxygenation, peroxidation may be used in special applications where contaminants (such as petroleum hydrocarbons and heavy metals) require oxidation to reduce toxicity and enhance degradation. The USEPA has also reported very successful applications of peroxidation as the sole remediating agent to completely remove pollutants within relatively short periods. Peroxide use is cost-effective for both soil and groundwater treatment and is better than continuous tilling as a means of aeration where conditions are conducive. It is especially useful in aquifers where it could be more cost-effective than other air sparging techniques. However, the use of peroxides (e.g. hydrogen peroxide, manganese peroxide or sodium peroxide) could be complemented by other methods in order to accelerate degradation. For example, in enhanced aerobic bioremediation technology for groundwater treatment, the use of hydrogen peroxide is considered to have the best potential for providing some of the highest levels of available oxygen to contaminated groundwater relative to other enhanced aerobic bioremediation technologies because it is infinitely soluble in water. Fentons' reaction is a continuous chemical oxidation reaction that occurs after addition of the iron and the hydrogen peroxide. Under typical conditions (5 to 25 parts of hydrogen peroxide to 1 part of iron, depending on COD/BOD (Bishop et al., 1968)) the reaction will generate hydroxyl radicals and release oxygen and hydrogen ions as in the following equations:

$$\mathbf{Fe^{2+} + H_2O_2 \text{ ----> } Fe^{3+} + .OH + OH^-}$$

$$\mathbf{Fe^{3+} + H_2O_2 \text{ ----> } Fe^{2+} + .OOH + H^+}$$

These hydroxyl radicals can oxidize the pollutants in several ways, as shown below:

- Addition: $\mathbf{{}^{\cdot}OH + C_6H_6 \text{ ----> } (OH)C_6H_6}$
- Hydrogen abstraction: $\mathbf{OH + CH_3OH \text{ ----> } CH_2OH + H_2O}$

- Electron transfer: $^{\cdot}$**OH + $[Fe(CN)_6]^{4-}$ ----> $[Fe(CN)_6]^{3-}$ + OH^-**
- Radical interaction: $^{\cdot}$**OH + $^{\cdot}$OH ----> H_2O_2**

During Fenton's reaction and especially in the application of chemical oxidation for groundwater remediation, parameters such as pH are adjusted to promote rapid removal of pollutants using the first two kinds of reactions, i.e. oxygen addition and hydrogen abstraction. In bioremediation, the third and fourth types of reaction that create ferric species and release oxygen and water are favoured. Maintaining pH at between four and eight is also critical to support microbial populations. So, the iron precipitates as its hydroxyl (e.g. Fe(OH)3) and catalytically decomposes the H2O2 to oxygen, potentially creating a hazardous gaseous build-up that must be taken into account in all system designs utilizing hydrogen peroxide, pure oxygen or ozone.

Other important factors include the concentrations of iron, which must at least 3 to 15 mg/l to favour release of oxygen in the system. The optimum pH for this reaction is between three and six. But the appropriate dosage ratio ranges from 5 to 25 parts of hydrogen peroxide to 1 part of iron, depending on the concentration of pollutants to be treated. Other important parameters include temperature, which rises during Fenton's reaction, but could be controlled by applying dosages at intervals. Therefore the application of hydrogen peroxide via re-injection of oxygenated groundwater has to be carefully considered in relation to using other solid or gaseous oxygen additives, which may or may not be complemented by bioagents, because there are several other limiting factors, such as hydraulic gradient, oil-degrading microbial communities, nutrients, soil permeability and the engineering of the system for delivery and monitoring (see Annex IV, Section vii; EPA, 2004).

The approach and calculation of oxygen needed for a particular design should be based primarily on total hydrocarbons to be remediated, other organic and inorganic demands (COD/BOD) in order to have an efficient delivery system. While vapour phase delivery of oxygen such as pure oxygen, air or ozone can deliver very high amounts of oxygen to the system design, the losses incurred due to over saturation in sub-surface water or losses to vadose zones (space between well hole and water table) and the susceptibility to fire hazards during delivery must be considered. Other solid oxygen releasing compounds like manganese peroxide may also be considered in certain conditions where the organic and inorganic condition of the soil or aquifer permits and the total costs of the design weighs in favour of this approach because treatments with solid phase oxygen-releasing compounds do not need as much system design as others and therefore are a much cheaper approach.

3.2.3 Phytoremediation

This technique refers to the use of plants and associated microorganisms for the in situ treatment of contaminated soils (White et al., 2005; Diab, 2008; Ndimele, 2010; Wuana and Okiemen, 2010; Dipu et al., 2011; Agbogidi et al., 2011; Kathi and Khan, 2011; Njoku et al., 2012). Grasses, herbs, shrubs, and trees are the general types of plants that have been considered in phytoremediation. A list of the types of plants and microorganisms that have been used can be found in Annex IV, Section v.

There are five basic types of phytoremediation:

i. Rhizofiltration: this is a water remediation technique whereby plant roots uptake contaminants. A commonly used plant is the grass *Vetiveria zizanioides* (Vetiver grass).
ii. Phytoextraction: this is a remediation technique involving uptake of contaminants from soils. Commonly used plant species are *V. zizanioides* (Vetiver grass), *Zea mays* (maize) and *Hibiscus esculentus* (okro).
iii. Phytotransformation: this involves degradation of pollutants through plant metabolism. Commonly used plants are sphagnum moss and *Vigna unguiculata* (cowpea).
iv. Phytostimulation: this involves stimulation of microbial action at the root zone and can be applied in water and soil. Rhizomes exhibit this ability.
v. Phytostabilization: this involves using plants to reduce the mobility and migration of potential contaminants or for stabilizing erosion-prone areas. Grasses of economic value such as *V. zizaninoides* (Vetiver grass) are commonly used.

The use of plants in one or a combination of the above processes will assist long-term rehabilitation and restoration of biodiversity due to their ability to support continuous degradation of contaminants via the catalytic action of plant enzymes. In this process, they release much-needed carbon that supports increased microbial activity, improves soil physical and chemical conditions, increases soil humus and enhances the adsorption of pollutants. Where biostimulation is applied, this plant action is replaced by microbial activity. However, soil or water conditions have to be at a toxicity level where these processes can occur. Therefore a preceding bio-treatment such as using biosurfactants and/or peroxidation is desirable to lower toxicity levels and promote phytoremediation, where conditions allow. For example, peroxidation requires the presence of iron to be effective. This is a promising approach for the Niger Delta, where iron levels are naturally high and several plants of economic value can be used for phytoremediation with potential economic benefits to encourage community engagement.

3.2.4 Rhizoremediation

This aspect deals with the application of filamentous fungi such as white rot, which uses the process of mineralization to degrade pollutants. White rot contains enzymes that can breakdown and mineralize hydrocarbons and many other pollutants into non-toxic forms. However, the challenge is that unlike microbes, fungi need extra bio-stimulants such as sawdust, plant debris or fertilizers. Therefore this is a more expensive approach that can be used only in specific areas and under specific conditions, depending on the recommendations of the bioremediation feasibility reports (Adenipekun and Fasidi, 2005; Obire et al., 2008).

3.2.5 Phycoremediation

This technique uses algae to enhance the degradation of contaminants. Algae are photosynthetic organisms that possess chlorophyll and very simple reproductive structure but have no roots, stem or leaves. They need carbon for photosynthesis and during this process oxygen is released that enhances bacterial activity and promotes degradation of hydrocarbons and releases carbon dioxide which is then used by the algae for photosynthesis. The challenge is that there is a risk that excessive growth can lead to algal blooms, causing a number of undesirable secondary effects. Therefore phycoremediation should only be considered for very specialized needs and in specific situations. However, algae may also be useful when used in a mixed media with other bioagents, in which case it is not a living plant that can grow and proliferate. Algae can also be useful for economic purposes such as biofuels, water treatment etc. Furthermore some algal species may be used for ecological monitoring; for example, the presence of desmids in water indicates clear (i.e. low turbidity) nutrient-poor waters.

3.2.6 Bioaugmentation

Bioaugmentation is the application of microbes and/or biosurfactants to enhance the degradation of hydrocarbon contamination in soil and water.

Many microbes can utilize a variety of substrates for growth but petrophillic bacteria are more specific to hydrocarbons. A new approach in bioaugmentation is to isolate and culture indigenous petrophillic bacteria for inoculation in their native soil in order to speed up natural degradation and achieve appreciable results within much shorter timeframes (one to four weeks depending on the type and scale of the spill). This approach addresses concerns about the use of bioaugmentation and the risks of introducing exotic or foreign bacteria. In general, the rate of adoption of bioaugmentation has been low, unless indigenous isolates are used for treatment.

Biosurfactants are complex low to high molecular weight lipid/protein complexes excreted by some microbes. Specific microbes are stimulated to produce biosurfactants when they grow in hydrocarbon-rich environments to enable them to uptake carbon more readily. According to several studies, *Pseudomonas sp.* and *Bacillus sp.* produce the most efficacious biosurfactants which enhance biodegradation. The compounds produced by *Bacillus sp.* are glycolipopepetides and glycolipids and those produced by *Pseudomonas sp*. are rhamnolipids. Several other bacterial isolates have also been known to do this to greater or lesser degrees as they target specific total petroleum hydrocarbon (TPH) fractions or polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). The challenge is to identify suitable microbes in the Niger Delta, isolate and deploy them in combinations such that they do not inhibit each other. Biosurfactants tolerate high temperature, salinity, and pH and are completely biodegradable. They increase bioavailability and thus create a wider surface area for enzymes to act on.

Enzymes are substrate-specific as well and those produced by oil-degrading bacteria such as the oxidoreductases, lipases, peroxidases, laccases, mono and di-oxygenases are best suited to catalyse hydrolytic reactions by lowering energy levels (i.e. creating intermediary less complex compounds or exchanging hydrogen molecules with oxygen, causing breaking of the hydrocarbon chain). Microbes or fungi secrete numerous enzymes to catalyse reactions until complete breakdown is achieved. They utilize the carbon and energies released during these processes to create proteins for growth and multiplication, utilizing also nutrients such as nitrogen, which is a primary element in their proteinous composition. This process eventually breaks hydrocarbon chains and converts complex toxic molecules into simple safe ones.

Generally only 10% to 40% of TPHs and even much less of PAHs and PCBS can be treated by biostimulation alone (i.e. addition of nutrients) mainly because of reduced bioavailability of hydrocarbons. Therefore the major advantage of the use of biosurfactants in bioremediation is that it greatly increases the bioavailability of contaminants, enabling better access to microbes.

The production of biosurfactants and even enzymes is reported to be relatively inexpensive if the microbes are grown on waste substrates or spilt petroleum products. This can take place either ex situ in bioreactors or in situ when stimulated by bioaugmentation. Most biosurfactants are produced aerobically but some can be produced under anaerobic conditions using bacteria such as *Bacillus licheniformis.* Anaerobically produced biosurfactants are potentially useful for treatment of underground water if suitable nutrient delivery methods can be achieved. In anaerobic conditions the key limiting factor is availability of nitrogen, which acts as an alternate electron acceptor under these circumstances. Some biosurfactants produced under aerobic conditions, such as rhamnolipids, have been found to work just as effectively in anaerobic conditions to increase bioavailability to micro-organisms. However, anaerobic respiration is much less efficient in degradation than aerobic, due to the capacity of oxygen to deliver far more energy during reactions.

Bioavailability of a hydrocarbon depends on the extent to which, and the rate at which, a particular hydrocarbon can be biodegraded by microorganisms. This compound–specific property is an expression of the poor hydrocarbon solubility, and its tendency to sorb to soil particles as a result. Relative bioavailability can be calculated using the organic carbon coefficient (K_{oc}), which helps to define the equilibrium between the hydrocarbon compound and the soil and water media.

3.3 Challenges for remediation through biological processes

The application of bioremediation techniques in the Niger Delta faces various challenges, among them the following:

- *Adverse effects of biostimulation*: The inappropriate use of nutrients (nitrogen, phosphates, and potassium), oxygen and water to promote degradation of contaminants by naturally-occurring microbial and fungal communities can have negative effects. Degradation may vary and sometimes fail as a result of the technique of application, overuse or prolonged use of nutrients or their use in disproportionate ratios. In groundwater, fouling and precipitation can lead to high maintenance costs.

- *Low bioavailability of hydrocarbons*: The success of degradation depends on bioavailability of the substrate.

- *Rich organic content of Niger Delta soil*: This causes hydrocarbons to bind more closely to the nutrient-rich soil thereby reducing bio-availability to the microbial communities for degradation.

- *Residual and recalcitrant hydrocarbons:* Aged spills (spills that have weathered and become more complex, forming complex c-chains and ringed benzene chains) and the long-term use of synthetic chemicals such as Triton X-100 in the Niger Delta have created complexes of hydrocarbons that are persistent and more difficult for the normal populations of bacteria to degrade (Mohan et al., 2006; Edwards et al., 2003).

- *The geophysical characteristics of the Niger Delta:* The presence of numerous rivers, creeks and streams as well as the high rainfall and flooding from the drainage basin contributes to the redistribution of pollutants from points of contamination to other areas, thereby increasing the extent of the impacts.

- *The import of alien microbes for bioaugmentation:* The use of microbial products that are not indigenous to the Niger Delta is not generally accepted by the Nigerian regulator.

- *Volatility of hydrocarbons:* Lighter hydrocarbons will evaporate and leave behind heavier hydrocarbons that are generally more difficult to degrade biologically.

- *Toxicity of hydrocarbons*: Aromatic hydrocarbons are often more toxic to microorganisms and hence reduce their efficacy in bioremediation.

- *Inadequate oxygen levels in soil and water*: Deficiency of oxygen is common in the soils and groundwater in the Niger Delta, prompting the need to seek the most cost-effective and efficient mechanisms of oxygen delivery in remediation. Hydrogen peroxide has been explored extensively by the USEPA (2004; 1998) as a solution to this challenge.

3.4 Other challenges for remediation in the Niger Delta

The discussion above has focused on challenges to remediation techniques in relation to the environmental conditions in the Niger Delta. Other challenges relate to anthropogenic factors such as sabotage, crude oil theft, artisanal refining, infrastructure failures, and SPDC internal environmental management procedures and policy issues. This Day Newspapers (2013), a prominent national daily in Nigeria, reported that the Honorary International Investors Council (HIIC), an organization of prominent foreign investors advising the Nigerian government on matters pertaining to economic development, has urged the government to curtail crude oil theft owing to the increasing threat to the country’s economy. In March 2013, SPDC announced a second closure of a pipeline (the Nembe Creek Trunk Line), following significant leakages caused by crude oil theft. This same pipeline had been shut in December 2011 following significant spills caused by crude oil theft then. Such spillages cause repeated impacts on the environment, which SPDC pledges to remediate. This is also a challenge for the Panel to seek effective ways to deal with situations such as these, whilst also encouraging government stakeholders to take measures to curtail the problem of sabotage and crude oil theft, as well as other illegal activities that are detrimental to the environment and the country’s economy.

3.5 Challenges posed by project area and anthropogenic influences

In the context of the Niger Delta, the size, age and vastness of the polluted area presents a serious challenge. In addition, there are four distinct ecozones with diverse biodiversity and interactions as well as significant groundwater contamination as reported in several studies (e.g. Niger Delta Environmental Survey (NDES) Phase Two Report (2004); United Nations Environmental Programme (UNEP) Environmental Assessment of Ogoniland, 2011). Continuing anthropogenic activity exacerbates impacts and inflicts economic losses on both the oil industry and local communities.

SPDC acknowledges that operational spills occur occasionally but also states that vandalism, oil theft and illegal refining cause several spills along the pipelines and frequently interrupt production. On the other hand communities continue to report loss of income-generating opportunities such as fishing and farming as a result of oil spills. There is also concern about communities' unsustainable expectations and over-dependence on SPDC for infrastructure and amenities that ought to be provided by government. However, there is more open-mindedness from all parties to explore approaches that are practical, cost-effective, efficacious and sustainable.

The Panel's assessment of community perceptions shows that irrespective of cultural diversity and multi-ethnicity, communities feel that the current practice of non-inclusion in approaches to remediation is unfair and unacceptable. There is widespread apathy, deepening poverty and restiveness. Prolonged pollution and continuous loss of income-generating opportunities have created a 'quick money syndrome', which is fuelled by over-expectations for compensation from the oil industry. However, there are opportunities to include these stakeholders in processes to support the remediation and rehabilitation of biodiversity and livelihoods.

3.6 Challenges posed by SPDC's internal environmental management processes

The speed of response is critical in handling new spills since one of the complications of delayed response is the formation of more complex hydrocarbons that are more difficult to degrade. It is also easier to contain and treat liquid spills before they form tar balls or asphaltenes as a result of weathering processes. Historically, delayed response encouraged a time lag that allowed spills and plumes to spread and/or seep deep into groundwater levels in certain soil types. Obviously, all these factors increase the scale and cost of remediation. So continuing the new response times of within 6 hours to 24 hours for Tier 1 and TIER 2 spills, and within 24 hours to 48 hours for TIER 3 spills is a great effort in the right direction. The Panel acknowledges the absence of in-country capacity to respond to TIER 3 spills within 48 hours, but agrees that SPDC should respond rapidly to alert government authorities and other countries or groups with such capacity, whilst also holding the basic tools that will enable some level of response as described in Annex IV, Section vi. Owing to the potential impact of Tier 3 spills on shorelines, beaches, barrier islands and mangroves, some level of aggressive bioremediation capability can be maintained in-country to minimize impact on these sensitive receptors. The materials and equipment recommended include biodegradable booms and boats to be deployed to protect beaches and shorelines and also appropriate amounts of bio-products (preferably enzymes and biosurfactants) sprayed on sea surface, beaches and shorelines to begin the degradation process, while waiting for more sophisticated equipment for containment. SPDC may also explore the application of new technologies and approaches that emerged during the Deep Horizon spill in the Gulf of Mexico to treat spills at the source as quickly as possible to minimize impact.

It was also observed that in some mangrove forests seismic and pipeline pathways have had a very significant environmental impact, causing disruption and stagnation of water in-flows to mangroves and thereby leading to the death of mangrove trees by asphyxiation. In other forests, these seismic/pipeline pathways have opened up thick jungles to farmers and hunters and other natural resource gatherers, leading to degradation of habitat and loss of biodiversity. The company could adopt new processes to re-channel water back to the mangrove forests and restore inflow as quickly as possible to prevent stagnation and asphyxiation of the mangroves that have been isolated by these pathways. It will also be expedient to plan this action within the timeframe when the pathways were created so as to minimize the death of the forests, quickly restore balance and support conservation of the ecosystem. Where damage is extensive during excavations, a mangrove nursery should be planned at the same time to enable the transfer of propagules to re-establish destroyed mangroves after the hydrology has been restored. These processes should be integrated into the construction activity period.

The IUCN–NDP also observed that the SPDC monitoring protocols need to be reviewed and tightened up to ensure that remediation guidelines are followed and implemented as directed. One such modality is to deploy independent specialist teams assembled on an ad-hoc basis when needed to ensure transparency and true independence, as several development agencies, such as the International Finance Corporation of the World Bank Group did in 2006 for the Chad-Cameroun Pipeline Project (International Finance Corporation, 2006).

While SPDC implements monthly monitoring for offshore produced water (PW) as indicated to the Panel during review meetings, there is a need for close continuous monitoring of PW by other international oil companies (IOCs) operating offshore. Oil companies need to adopt this as a general approach to monitor conditions and collectively plan periodic remediation to boost the natural marine or land environment, even without the occurrence of major spills. Produced water does contain small amounts of PAHs of between about 0.040mg/l and 3mg/l (Oil &Gas Producers (2005). Intermediate PAHs derived from congeners have been seen to be far more toxic than the mother compounds and increase the total PAHs content drastically. This concentration of total PAHs in PW is mainly constituted of napthalene, phenathrene, and dibenzothiophene (NPDs) and their derivatives 2-3 ring alkylated PAHs. The abundance of these alkylated derivatives is more than in the parent compounds. For this reason and since 2004, there has been close monitoring of the 16 USEPA PAHs in the North Sea. Data from this offshore platform show that the vast majority (about 97%) of PAHs in produced water are of BTEX (benzene, toluene, ethylbenzene and xylene), about 3% of 2- and 3-ring PAHs (i.e. napthalene, phenathrene and dibenzothiophene (NPDs)) and a variety of larger ringed and complex PAHs making up less than 0.2%. Thus the abundance of these NPDs and their derivatives as well as the potential impact on marine environment is a cause for concern. Estimates of produced water discharge on the Norwegian shelf predict an increase that will peak sometime between 2010 and 2014, reaching a maximum of about 200 million l/yr. Therefore the North Sea offshore discharge has been under periodical monitoring for some time to determine future approaches to its impact in the marine environment (Pampanin and Sydnes, 2013).

SPDC introduced this monitoring especially in view of the backlog of impacted sites along the shore and current approaches in situations where offshore smaller spills below TIER 3 may be allowed to dissipate by natural wave and wind action.

3.7 Challenges posed by policy standards

Data collected from selected sampling sites in Soku by the IUCN–NDP team showed concentrations of chemicals of special concern (CoSC) above the remediation intervention levels stipulated in Table VII-F1 of EGASPIN (See Annex III). Furthermore, the standards in the revised DPR-EGASPIN (2002) levels, which are reflected in SPDC's Remediation Management System Version 3 (2011), established targets and intervention levels of pollutants that are higher than those specified in other countries such as Canada (see Annex III). International guidelines for best practice in biodegradability of chemicals of special concern have been published by the International Standards Organization and the World Health Organization (WHO) and the Organisation for Economic Cooperation and Development (OECD) (see OECD, 1995). Countries such as Canada and the USA have stringent target levels for CoSC that are site-specific. In addition to soil-specific target levels, EGASPIN needs to have target levels for the degradation of PAHs in surface water, which are of significant concern due to their toxic, mutagenic and carcinogenic nature. Comparisons of EGASPIN soil, surface and groundwater standards with those in place for Alberta, Canada and the soil remediation levels (target values) of TPH of some USA states, shows that most are lower, more stringent and site-specific. However, EGASPIN target levels compare favourably with standards in the United Kingdom and the Netherlands, especially as the UK standards did not indicate PAHs levels for soil and groundwater, and the Netherlands standards indicate values for only 10 of the 16 CoSC for groundwater alone. But in the case of the Alberta target values, the Canadian Council of Ministers for Environment endorsed a very wide range of TPH and PAHs target values for soil, surface and groundwater, following intensive reviews (Alberta Environment, 2010). So even though EGASPIN policy was last reviewed in 2002, it still has stricter standards in some respects than other countries reviewed. Though EGASPIN standards for heavy metals are higher than other countries reviewed it may be that it took into account the naturally high levels of iron and other heavy metals in the region. Also for the aromatic compounds, toluene, xylene and phenol, the soil and groundwater intervention values in EGASPIN are higher than those provided by the Dutch guidelines. EGASPIN also has target and intervention values, which has been retained in the IUCN–NDP recommendations to give SPDC flexibility in prioritizing the selection of sites for remediation from the backlog of impacted sites in the Niger Delta.

There are fundamental gaps in the policy frameworks for biodiversity conservation as it relates to the oil industry in Nigeria. First, the regulatory guidelines for conservation and management of biodiversity are not stringent enough and mostly absent from EGASPIN protocols, though it appears that the EGASPIN protocols were delineated for only chemical pollutants. Secondly, there are several government agencies that have similar mandates for regulating biodiversity conservation but there is a need for more communication between them to support a wider collaboration with the rest of the oil industry. Finally, the resources of all the relevant regulatory agencies are too low and need to be boosted by the government.

However, it should be recognized that some regulators such as Federal Ministry of Environment and National Oil Spill Detection and Response Agency (NOSDRA) have been making efforts to bridge this gap. In 2010, the Federal Ministry of Environment (FMEnv) expanded its guidelines on Environmental Impact Assessment to include site-specific baseline measurements as well as socio-economic and public health baseline information on telecommunications and other industry projects. The National Oil Spill Detection and Response Agency (NOSDRA) also improved its guidelines to recognize and strengthen local capacity to tackle remediation. In Port Harcourt, Rivers State, in 2012, they supported training and awareness programmes for cultivation and production of kenaf sorbents locally as a community motivated project to support response to remediation.

Chapter 4

Recommendations

4.1 Recommendations for SPDC's internal environmental management

SPDC's internal environment management priorities for oil spill management and rehabilitation of old and aged oil spill sites in the Niger Delta should evolve and expand to accommodate key biodiversity values of relevance to SPDC's business and the local communities involved. Integrating biodiversity priorities in the response and remediation of such oil spills will help ensure that SPDC's internal systems are fit for purpose and much more responsive in terms of the timeliness of actions and the scope of application. The Panel proposes a number of actions below, all with an eye on the longer-term vision for improved spill management, remediation and biodiversity rehabilitation.

Recommendation 4.1.1: Redefinition of receptors and other relevant approaches used in the business model to include representation of key native biodiversity and associated biophysical and social values

The current parameters determining SPDC's oil spill response interventions do not properly extend to biodiversity issues. In addition to farmlands, they should include habitats of key relevance to the Niger Delta biodiversity such as mangroves, shorelines and barrier islands, freshwater marshes, and lowland forests. Interventions also need to recognize and take into account biodiversity hotspots. This approach will ensure that the response to oil spills and their longer term rehabilitation can accommodate key biodiversity aspects**.**

Recommendation 4.1.2: Redefinition of monitoring protocols

SPDC should introduce independent monitoring teams comprised of professionals from relevant backgrounds and selected on an ad hoc basis (enhancing transparency) to undertake scheduled visits in order to check more stringently the target levels for CoSCs, in order to support rehabilitation of biodiversity and habitats. Even with stricter monitoring prior to first sign-off, the first few months are inadequate for biodiversity rehabilitation, therefore monitoring needs to continue with annual monitoring for up to a period of three years to allow enough time for habitat recovery in accordance with the protocols of the IUCN–NDP Outcome Success Matrix (see Annex III) and the reappearance of biodiversity before final sign-off. This activity could also be part of the wider biodiversity plan recommended in Section 4.5.

Recommendation 4.1.3: Review and revision of assessment feedback cycle to refine company actions on a rolling basis

There is a need to ensure that within the company's environmental management procedures, there is a regular, efficient and effective feedback cycle that loops field experience and monitoring into future spill management and decision-making processes. This will help ensure feedback of experiences from the field in order to build up SPDC's practices of biodiversity rehabilitation over time.

Recommendation 4.1.4: Review of some current activities in RMS 2011

The SPDC Remediation Management System 2011 contains detailed instructions on mechanical remediation activities that have been the basis of remediation activities for the Niger Delta. The Panel notes that:

- RENA may be suitable where spills are spread out to a thin spatial distribution of less than 10 centimetres on land, which enables better interaction between the electron donors (pollutants) and acceptors such as nitrates and sulphates (Bauer et al., 2008). Fresh and residual hydrocarbon pollutants are toxic to micro-organisms and the application of RENA to improve nutrient availability to increase populations can only achieve about 40% remediation, as increasing toxicity of metabolites (formed by incomplete degradation) inhibits or kills off viable populations of oil-degrading organisms. Even for small spills, it is desirable to use bioagents (especially enzymes) to increase degradation exponentially. However, the nutrient criteria for RENA requires that soil conditions be known prior to application, in order to use the correct ratios of carbon: nitrogen: phosphates (100:10:1) in groundwater (USEPA, 2004), or ratio of nitrogen: potassium (44g:22g in 650g of oxygen) in soil conditions (Kosaric, 2001). This process requires close tracking to ensure that potassium levels do not exceed the lethal concentrations of above 1%, because in excess of 1% potassium is toxic to micro-organisms and would significantly deplete the capacity of oil degraders (Vyas and Dave, 2010).

- Hydrogen peroxide is recommended as a less expensive and easier oxygenation option in aerobic conditions due to Fenton's reaction, which should be triggered by the natural high content of iron in the Niger Delta. A dilute solution of 6% of hydrogen peroxide is typically used in remediation and could potentially deliver as much as 50mg/l of oxygen (Cline et al., 1984; Vicente et al., 2011). It could be used with stabilizers such as chelating agents where conditions necessitate, but generally conditions in the Niger Delta are favourable due to naturally high iron content. Kanaly and Harayama (2000) observed that in conducive environments (with adequate and appropriate nutrients and biocatalysts), the metabolic pathway of a hydrocarbon compound will degrade quickly to carbon dioxide and water. In adverse conditions, metabolites of the hydrocarbon could persist until the situation becomes conducive. For example, the metabolic pathway for fluoranthene showed the presence of more than 10 to 14 metabolites during aerobic bacterial degradation. These metabolites could persist and increase toxicity of environment unless the condition that caused the slowing down of degradation improves. In field applications, biodegradation activity consumes oxygen rapidly and oxygen deficiencies may occur intermittently so hydrogen peroxide could be a quick way to re-oxygenate such conditions. In anoxic respiration the rate of degradation is slower and energy yield lower, but denitrifying bacteria would use nitrates, while sulphate-reducers or iron-reducing bacteria would use sulphates or iron as alternate electron acceptors for degradation. Anaerobic respiration will continue for as long as these elements (iron, sulphates and nitrates) are present in adequate proportions for the respective microbes. For example, the optimal concentration for iron (III) in groundwater may be less than 2mg/l or up to 10mg/l, while carbon, nitrogen, and phosphates require a ratio of 100:10:1 for this action to be sustained. (USEPA, 2004; Kosaric, 2006).

- Phytoremediation is not effective in heavily contaminated conditions due to the fact that chemical and physical properties of the soil kill the plants, or severely limit their growth and effectiveness. Therefore the first step following an oil spill is to reduce oil concentrations using the guidelines provided in Annex III, before applying phytoremediation techniques.

- Use of non-native plants in reforestation threatens biodiversity as the non-natives can be very aggressive in new environments where their natural limiting factors are absent. This severely limits the chances of recovery to conditions prior to oil spills. However, in some cases, sterile, transgenic non-native plants may be used under strict control. *Vetiveria* sp. have been found to be useful in these circumstances when sterilized.

- Use of heavy equipment to turn over mangrove soil transfers pollutants deeper into the soil strata, where conditions are usually anoxic. As a consequence, the oil can remain unchanged for decades. In addition, heavy machinery alters surface water drainage patterns in mangroves thus impeding natural regeneration of the forest and causing degradation and death of the habitat. Therefore the use of heavy machinery should be discontinued.

- Use of synthetic surfactants should be avoided because they are not as completely degradable as biosurfactants, which are produced naturally by some microbes.

- Discourage the use of transgenic plants as this could lead to complete loss of natural biodiversity due to colonization (especially in mangrove forests) by more aggressive non-native species**.**

- The recommended guidelines in Annex III, Section iii are based on comparisons with standards in other countries, WHO limits for human health, USEPA guidelines for PAHs and the National Oceanic and Atmospheric Administration (NOAA) target levels for sensitive biodiversity. Field observations guided by the Panel's Outcome Success Matrix as well as comparisons with calculated degradation kinetics could be used to determine new target sign-off levels, because the current use of EGASPIN standards (last updated in 2002) needs some modifications.

- SPDC should conduct stricter monitoring of sites before sign–off as contractors may not have conformed to current remediation standards, as seen in some cases.

- Owing to the challenges of addressing offshore spills smaller than TIER 3, continue monthly monitoring of PW and encourage other IOCs to introduce periodical monitoring of water columns offshore to monitor PAHs total content, owing to the carcinogenic/mutagenic properties of PAHs in produced water and the tendency of PAHs to create intermediates that are more toxic than the congeners and which could drastically increase total PAHs numbers in the environment (Oil and Gas producers (2005).

4.2 Recommendations for oil spill response procedures

There are considerable challenges involved in responding to new oil spills including issues of security, occasional fire delays, delays in obtaining freedom to operate in some communities, delays caused by access to spill sites/location due to the nature of the terrain and the lack of adequate communication, and inadequate coordination between communities, regulators and companies. There is therefore a need for continuous reviews of approaches to oil spill response in order to maintain current response timeframes and perhaps improve effectiveness in the future.

Furthermore, the current intervention levels for pollutants, remediation standards and monitoring techniques are inadequate to achieve restoration and rehabilitation of biodiversity and habitats. The time lag in activating remediation processes may be attributed to bureaucracy but there is room to improve on reporting, scoping, containment, recovery, local availability of materials, engagement of contractors and remediation techniques.

The overall goal of ecosystem restoration is to return the impacted site back to near pre-spill conditions. Remediation management systems (RMS) prepared by SPDC provide environmental standards for the remediation of oil spill impacted sites and these standards are in line with revised DPR-EGASPIN (2002) levels; but higher than international standards seen for TPH levels in the USA and Canada (see Annex III). A new guideline should be developed for ecosystem rehabilitation in the Niger Delta, to include a wider range of pollutants, CoSCs, especially for PAHs in soil and groundwater. Soil and groundwater data collected from the impacted sites in Soku by the Panel showed concentrations of CoSC above the remediation intervention levels stipulated in Table VII-F1 of EGASPIN (Annex I, Section c: Biophysical Data for Soku).

The following recommendations are introduced to speed up deployment and implementation of more comprehensive remediation plans, while discontinuing ineffective processes. These actions are recommended to enhance and support procedures in the company's RMS 2011 document.

Recommendation 4.2.1: Speed-up response to oil spill incidents

- Continue with SPDC's revised processes to contain Tier 1 and Tier 2 spills within 24 hours; however the target response time for containing Tier 3 spills (i.e. within 48 hours) is not feasible for SPDC at this time because there is inadequate in-country capacity supported by the Nigerian government. Nonetheless, SPDC should continue to explore viable options to reduce the spread and scale of secondary impact in the earlier hours of the spill when it is lighter and much less viscous and therefore flows faster and spreads rapidly. Tier 3 spills are generally more technically challenging and would require concerted efforts of experienced and well equipped international groups to support the oil companies in Nigeria should this situation occur in the future. The most important lessons from the Deepwater Horizon spills in the Gulf of Mexico were that new methods of containment and treatment were developed and most interestingly, an approach to tackle spills from the well head source. However, instead of toxic dispersants that were used in that case, safe bioagents (enzymes and biosurfactants) could be sprayed directly at the well head (where applicable) to assist degradation more rapidly and minimize longer term impacts on shorelines and beaches. If done correctly, this method should degrade the spill starting from the source and is potentially a rapid degradation approach for Tier 3 or any other spill that can be tackled at source. The impact on oxygen levels and therefore marine life would be minimized as wave action quickly replenishes nutrients and oxygen. On land, oxygen levels may be replenished by using hydrogen peroxide as the quickest, most efficient delivery method in many conditions. Protection of beaches and shorelines with sorbent booms and inflatable booms are also recommended to continue minimizing and controlling impact. Beaches and surface water could be sprayed with bioagents (enzymes and biosurfactants), while tarballs and clumps of oil may be picked off the beaches manually, to be remediated ex situ. (See Annex IV, Section vi for an outline of activities for Tier 3 spills and Annex IV, Section ii for remediation activities in mangroves affected by large scale spills).

- Follow up immediately with recovery of oil and commence deployment of remediation team to carry out Remediation Feasibility Investigation (see Annex IV).

- Initiate and complete Remediation Feasibility Investigations to ascertain procedure for bioremediation within seven days. Use the Guide for Bioremediation Feasibility Investigation shown in Annex IV, Section i.

- Apply remediation protocols (see Annex IV, Section iii) to define appropriate bioremediation approaches.

- Apply remediation techniques to support development of appropriate approaches in specific ecosystems. (Annex IV, Section iii, Overview of Bioremediation Techniques and Section ii for Mangrove Ecological and Hydrological Restoration).

- In offshore situations, introduce monitoring of water columns for the 16 USEPA PAHs especially in view of increasing concerns about the content of PAHs in produced water (PW) and their impact on the marine environment.

- Increase the number of oil spill response bases (including remediation materials) across the Niger Delta and maintain an adequate stock of requisite materials (such as inflatable booms for containment, recovery materials, biodegradable sorbent booms, biosurfactants, enzymes, nutrients and peroxides). It is pertinent to note that due to the sensitivity of materials recommended for remediation, it is important for SPDC to hold and issue specialized stock to contractors when required, in order to maintain Quality Assurance and Quality Control.

- Engage the remediation contractors within 14 days of the Bioremediation Feasibility Investigations described in Annex IV, to commence work immediately after feasibility investigations/design of approach has been done.

- Initiate socio-environmental processes to include community engagement procedures where applicable (see Annex III).

Recommendation 4.2.2: Redefine nature of treatment of oil spill sites bringing it up to acceptable and comparable national standards that support quicker ecosystem recovery

- In support of ecosystem recovery, regulatory agencies should review target levels/standards of CoSC to levels that can support ecosystem recovery by comparing EGASPIN standards with those of other countries, such as Canada (see Annex III) as well as reviewing international guidelines for testing of CoSC published by OECD in 1995, and EC in 2010, and calculating degradation kinetics using local assumptions to achieve Nigerian specific standards for interim sign–off.

- Using the Bioremediation Feasibility Investigations (in Annex IV, Section i), select appropriate remediation methods for the relevant ecosystems, to boost rehabilitation of biodiversity and habitats.

- Complete remediation process to the point of secondary remediation within three to six months (depending on the site–this is not applicable to sites with re-pollution), to enhance success of ecosystem recovery.

Recommendation 4.2.3: Expand remediation mechanisms to include restoration and rehabilitation actions that will expand the socio-environmental activities to support rehabilitation of biodiversity and livelihoods

- After primary treatment to reduce toxicity, continue into secondary and tertiary remediation treatments (phytoremediation/rhizoremediation) using economic crops (such as kenaf, cassava, Jatropha, cowpea etc (see Annex IV, Section v) for industrial consumption in the first phase.

- Continue into rhizoremediation with economic crops fit for consumption when pollutant levels (especially CoSCs) are considered safe for consumption.

- Appropriate and sustainable income-generating approaches should be adopted for phytoremediation/rhizoremediation. These could include local production of kenaf sorbents derived from *Hibiscus cannabinis*, biogas production derived from *Jatropha* sp., production of industrial starch derived from cassava, etc. (Agbogidi et al., 2011; Njoku et al., 2012; Ndiemele, 2010; Wuana and Okieiman, 2010; Tanee and Love, 2009). These activities should involve the communities and the project design should have an exit strategy as recommended in 4.4 below.

- Where there is historical degradation of mangrove forests and it is related to seismic and pipeline pathways, examine other ecological conditions but apply hydrological restoration first before any further remediation activity is considered. (see Annex IV, Section ii for appropriate methods).

- In other historically impacted sites in the Niger Delta, assess the biophysical situation and then implement secondary remediation measures under the socio-environmental strategy, where the conditions permit (Annex IV, Section iii).

Recommendation 4.2.4: Introduce procedures to redefine and reinforce best practice for the remediation team

- Using the suggested guidelines for interim sign-off, verify that CoSC are within the new and more stringent limits to support rehabilitation of ecosystems in the long term (See Annex III).

- Train remediation teams on new approaches in socio-environmental strategy that include community participation and engagement (Annex IV, Section iii).

- Use Protocols in Annex IV, Section iii as a guide for remediation based on scientifically proven methods.

- Establish standardized rates for bioremediation and define appropriate site-specific monitoring activities to meet any newly established interim sign-off standards e.g. *Bacillus subtilis* and *B. megaterium*.

- Introduce wider use of bioagents isolated from indigenous non-pathogenic organisms (*Bacillus subtilis, Bacillus megaterium*) to boost and support natural microbial activities for degradation and elimination of pollutants, the preference being for less toxic, fully biodegradable biosurfactants and non-pathogenic micro-organisms. Examples of some biosurfactants and their application are provided in Annex IV, Section iv.

- Broaden the availability of seedlings for phytoremediation/rhizoremediation (see Annex IV, Section v). The emphasis for plants used in phytoremediation will be naturally-occurring plant species indigenous to the Niger Delta region in order to reduce the invasiveness of foreign species and conserve the inherent nature of the region. This approach will further encourage the return of native species. The use of non-native plants should be discouraged as their effects are seen where mangrove forests have been re-colonized by more invasive *Nypa* palms, thus changing the micro-environment permanently. Studies of plants native to the Niger Delta ecosystems abound and the use of these should be encouraged going forward.

- Introduce periodical monitoring of offshore produced water by periodically measuring water columns to monitor PAHs total content, owing to carcinogenic/mutagenic properties of PAHs in produced water and the tendency of PAHs to create intermediates that are more toxic than the congeners and which drastically increase total PAHs numbers in the environment with its attendant potential impact on marine life.

Recommendation 4.2.5: Introduce annual monitoring post remediation to reduce residues of chemicals of special concern (CoSC) and support biodiversity rehabilitation

- Introduce two sign-off levels as a means to support restoration of biodiversity. The first regulatory sign-off should be based on more stringent target levels especially for CoSC as would be indicated in the proposals for revised guidelines based on calculations and field trials.

- Ensure adherence to improved target levels (based on calculations and field trials) to significantly reduce toxicity levels and promote re-establishment of biodiversity and habitats through successful cycles of phytoremediation (see Annex IV, Section v).

- Introduce an annual monitoring within three years post-remediation for ecosystem recovery before internal sign-off. This will only apply to areas where recontamination has not occurred.

Recommendation 4.2.6: Introduce conservation and management of pristine areas and biodiversity hotspots

As in all deltaic regions, the Niger Delta is a very rich resource for the sustenance of natural resources to support livelihoods. Efforts should be made to conserve and manage these resources sustainably for the benefit of the environment and its people.

IUCN and its Members in Nigeria have implemented strategies for the conservation and management of natural resources in various ecosystems of the world and IUCN is a repository of some of the best strategies in the conservation of biodiversity and ecosystem management. The Panel recommends that stakeholders:

- Introduce strategies for effective conservation of biodiversity and pristine areas

- Select appropriate sites and develop projects that aid capacity building for the conservation of biodiversity and pristine areas

- Select appropriate sites to build capacity for the development and implementation of blue carbon projects

- Build the capacity of CBOs to implement a project for local production of Kenaf 100% biodegradable organic sorbent materials for bioremediation as an integrated socio-environmental plan for communities

- Adopt IUCN best practice for conservation of endangered species, forests and areas of special interest such as critical fish habitats, Important Bird Areas (IBAs) and nesting sites for sea turtles

- Select appropriate sites to develop potential for conservation of nesting sites for migratory birds in the Niger Delta

- Map fish breeding areas within mangroves as well as sites for artisanal fisheries

4.3 Recommendations for bioremediation and rehabilitation procedures

The Panel recommends a redefinition and evolution of biological remediation approaches as the safest, most efficacious and cost-effective ways of in situ remediation, targeting key habitats through the systematic application of methodologies to support ecological restoration. The new procedure will be implemented in phases and its application will depend on a number of factors as outlined in specific preliminary bioremediation feasibility reports for particular sites (see Annex IV, Section v).

The major target habitats include swamps, creeks, mangrove forests, shorelines, farmlands, soil, groundwater, fresh/brackish water bodies and marshes.

Recommendation 4.3.1: Expand the range and improve the efficiency and effectiveness of remediation approaches targeting major habitats drawing on known best available scientific information and experience

Different phases of remediation and rehabilitation are recommended:

Phase 1: Remediation process (short term: 3 to 6 months)

The objective of this phase is to reduce in situ toxicity levels and increase bioavailability of hydrocarbons to microorganisms in order to enhance rapid biological degradation. This may require addition of nutrients (biostimulation) followed by bioaugmentation. The following procedures will reduce toxicity and stimulate biodegradation:

- *Peroxidation* (Greenburg et al., 1998) with hydrogen peroxide (catalysed by Fenton's reagent where required) is a first application to improve conditions for bioremediation in groundwater or soil as a cost-effective detoxifier where conditions allow (see Chapter 3 and Annex IV, Section iv).Typically a dilute solution of 6% is used in bioremediation for chemical oxidation processes of iron. In cases of fresh spills and where there is access to the source of spill on ground, hydrogen peroxides and other bioagents are applied to promote oxygen supply.

- *Increasing Bioavailability:* after peroxidation apply biosurfactants from non-pathogenic bacteria isolated in situ (lipopeptide (or surfactins) of *Bacillus subtilis*, and glycolipopetides of *Bacilllus megaterium*) using the appropriate application in specific habitats (Annex III and IV, Section iv; and references Das and Muherjee, 2007; Perfumo et al., 2001; Das and Muherjee, 2007). For safety reasons and to reassure the regulator, only bioaugments of these two species (*B. megaterium* and *B. subtilis)* should be used for bioaugmentation, while biosurfactants of these and any other biosurfactant produced ex situ may be used.

- *Stabilizing hydrocarbons in water bodies to increase bioavailability:* use optimum performance biosurfactants such as high performance Rhamnolipids of *Pseudomonas aeroginosa*, which act with equal efficacy in both anoxic or aerobic conditions; glycolipids, glycopeptides or lipopeptides which may be produced from ex situ isolates/cultures of non-pathogenic bacteria such as *B. Subtilis, and B. Megaterium* or the glycolipopeptides of *Corynebacterim kutscheri,* which is pathogenic to rodents and could be useful in mangrove regeneration and other phytoremediation approaches to reduce or control the challenges of losing seedling and propagule nurseries to rodents.

- Biosurfactants stimulate other microbes to produce biosurfactants in situ and also promote microbial activity. However, some like Acinetobacter RAG1 may inhibit action of other Acinetobacter sp and therefore it is critical to analyse microbial colonies prior to use or specific treatment. This is applicable in soil and water bodies whether they are freshwater, brackish or salty (see Annex III and IV, Section iv; and references Das and Mukherjee, 2007; Das et al., 2008; Gerson and Zajic, 1978; Banat, 2000; Kang et al., 2010; Perfumo et al., 2001; Das et al., 2009).

- *Accelerated degradation activity* can also be achieved with enzymes isolated from oil-degrading bacteria. Bioenzymes are catalysts that kick off reactions that lead to degradation of hydrocarbons in series of oxidation-reduction reactions, during which oxygen (aerobic action) or another suitable electron acceptor, such as nitrogen or iron (anaerobic activity) is exchanged to break carbon chains, to form intermediate metabolites before final break down into carbon dioxide and water. These bioenzymes are hydrocarbon-specific and sometimes oil-degrading bacteria or some plants will cometabolize several other hydrocarbons depending on the type of enzymes produced. Some plant families, such as *Gramineae, Fabraceae* and *Solanaceae* are used in phytoremediation because they are able to degrade hydrocarbons by secreting oxidoreductases. The group of enzymes known as mono and di-oxygenases and the lipases are the most important in biodegradation of hydrocarbons due to affinity for hydrocarbon molecules (Karigar and Rao, 2011).

- *Bioaugmentation* (with nutrients): add nutrients in appropriate ratio based on scientific studies for optimum performance of microbes such as N (44g), K (22g), H_2O_2 (650g) (see Annex III and reference Kosaric, 2001).

- *Bioaugmentation with in situ isolates/cultures:* it is recommended that sorbents, soil, or surface or groundwater be inoculated with cultures of non-pathogenic isolates of *B. subtilis* and *B. megaterium* based on site-specific needs such as oil-degrading microbial populations, levels of hydrocarbons and analysis of organisms or situations competing for oxygen (Sheng, 2008; Thavasi et al., 2008).

- *Land farming processes:* this is most appropriate for soils or shorelines and beaches and should continue after detoxification and/or increase in bioavailability with use of organic materials like SpillSorb, kenaf or other 100% organic materials mixed in appropriate ratios with hay or grass and tilled into soils. These may or may not be inoculated with in situ isolates/cultures depending upon site conditions.

- *In water bodies:* with the exception of land farming techniques, the applications described above are adequate for water bodies when applied in strict accordance with instructions (see Annex IV, Section iii). Owing to the threats to livelihoods, remediation in water bodies should be rapid, followed by rapid deployment of strategies to re-stock fisheries and resuscitate livelihoods.

- *In creeks:* the first approach after/or simultaneously with containment/recovery processes should be application of biodegradable booms to soak up excess oil (this has an inherent wicking action) and reduce detoxification; otherwise stabilization of hydrocarbons in water (to increase bioavailability) should commence immediately after containment and recovery of oil. When applied with enzymes, the stabilization process of biosurfactants also has the advantage of causing hydrocarbons to float, thus enabling near surface activity and reducing problems associated with de-oxygenation brought about by the increased microbial activity.

- *In groundwater:* peroxidation is safe (ITRC, 2005) and cost-effective but in-depth assessments of conditions suitable for oxidation are needed before application of bioavailability and/or bioaugmentation processes in groundwater. Several factors must be considered including hydraulic gradient, presence of appropriate oil-degrading community, all other factors competing for oxygen including inorganic compounds, humus, microbes and physico-chemical property of the aquifer. This will determine which of seven types of enhanced aerobic technologies may be used, though hydrogen peroxide is considered to have the highest potential to deliver oxygen efficiently in groundwater technologies because of its high level of solubility (EPA, 2004).

The monitoring of groundwater remediation is crucial and certain parameters such as oxygen levels in subsurface and unsaturated zone should be conducted frequently. Other indicators of ongoing remediation, such as increase in oil-degrading community, high content of lipases and oxygenases, activity in hydrocarbon concentrations, presence of metabolites of the hydrocarbons and others factors are also necessary to monitor activity, detect problems and correct them.

In anoxic conditions, presence of lipopeptide surfactants of *Bacillus lichenyformis* or rhamnolipids of *Pseudomonas aeroginosa,* will aid degradation of pollutants and they work with equal efficacy under anoxic or aerobic conditions**.** The presence of inorganic minerals such as nitrates, iron, sulphates also aids anaerobic degradation. Similarly, monitoring protocols should compare ongoing activity with the baseline conditions observed prior to remediation activity (see Annex III and IV, Sections iii, iv, vii; and references EPA, 2011; Prasanna et al., 2005; Javaheri et al., 1985). Successful commercial applications have been documented by Solvay Interox—a company which has applied hydrogen peroxide for soil and groundwater remediation (see Annex IV, Section vii and Annex V).

For the treatment of other water bodies polluted by hydrocarbon, the use of similar products as mentioned above is applicable. However, other site-specific issues such as access to sites or formation of tar balls may force a change of products or combinations of other techniques stated in Annex IV, Section iii.

Recommendation 4.3.2: Include biodiversity rehabilitation along with remediation activity using trials on the major habitat types

Phase 2: Remediation process (6 months onwards)

Following the bioremediation process that has reduced contamination levels, the next stage should be rehabilitation of habitats and biodiversity, which will take from six months upwards. At this stage phytoremediation can be initiated as a technique to further reduce the petroleum hydrocarbon levels and at the same time initiate the rehabilitation process.

In phytoremediation the emphasis will be on naturally-occurring, indigenous species of high economic value. Such plants include the following:

- *Hibiscus cannabinus* from which sorbents (kenaf), drinks, mats, gazebo roofing sheets, fuelwood and a host of other commercially viable products may be derived;

- *Manihot esculenta* (cassava) from which starch, fodder material and local dough (garri) are derived; and

- *Medicago sativa* (alfalfa) used as a very popular medicinal palliative for cancer and diabetic patients.

Other plants commonly used in phytoremediation include stimulators of rhizosphere biodegradation, such as, different types of grasses (Graminae, which have fibrous root systems that form a continuous dense rhizosphere that is required for harbouring the biodegraders and other conditions necessary for rhizo-remediation). Grasses that have been known to do well in this case include wheat grass, rye grass, fescue, vetiver and many others (Kathi and Khan, 2011). Annex IV, Section v shows some plants used in phytoremediation.

Some reasons for selecting plants for secondary treatment (rehabilitation) by phytoremediation include:

- Effectiveness in phytoremediation by their capability to support habitat restoration, which can be assessed by scientific trials referred to in Annex IV, Section v;
- The economic value and potential to create income-generating opportunities; and
- The familiarity of the species to the communities.

The application of phytoremediation after primary treatment and detoxification is an integrated socio-environmental approach for rehabilitation of biodiversity and habitats. It proposes to generate income-generating opportunities for communities in a collaborative effort.

The rehabilitation programme should be self-sustaining in the long term, with a clear exit strategy. The purpose of this programme is to build capacity for local production of sorbents and biosurfactants, nurseries for seedlings and other related activities to support the ongoing processes of bioremediation and phytoremediation that will sustain biodiversity and habitat restoration. It will also ensure restitution of livelihoods by encouraging activities such as farm settlements and aquaculture.

Recommendation 4.3.3: Initiate programmes to rehabilitate critical habitats including mangroves

Owing to their peculiar nature and fragility, mangroves require specially-defined restoration activities. Since they dominate coastal intertidal areas that are subject to stranding and trapping of oil, mangroves are considered to be the most sensitive of all ecosystem types to oil spills. Mangroves are vulnerable to long-term effects of oil spills due to the extremely high organic content of sediments and anoxic conditions that could retain pollutants in their original state for decades.

Natural regeneration of mangroves is very difficult under the stress conditions that are predominant in the Niger Delta. These include several anthropogenic activities such as dredging, oil theft, illegal refining/transport of crude oil, constant use of speed boats, operational spills and accidents. Another factor is the cutting of pipeline right-of-way and seismic lines without immediate hydrological restoration.

Therefore, mangrove remediation and rehabilitation require engineering and ecological approaches:

- To prevent injury to the mangrove forest following an oil spill, mechanical exclusion and recovery of spilled oil are recommended. For ‘barrier methods’ to work in real-time oil spill response, pre-planning for placement of sufficient booms is critical. Boom effectiveness will depend on physical characteristics of impacted mangrove areas, type of spilled oil, as well as seasonal changes in water levels, winds and tides. It is appropriate to do nothing when natural oil removal is rapid, when mangroves are inaccessible, or where clean-up will cause more harm than good.

- Hydrological restoration must take place to revive mangrove forests killed by stagnation and asphyxiation when seismic and pipeline construction activities have occurred. Hydrological restoration channels that will mimic natural water flow must be re-established to support regeneration or revival of a dying forest.

- Subsequently, ecological restoration as described in Annex IV, Section ii should follow.

- In cases of oil spills, bioremediation following site-specific analysis and plans using the guide in Annex IV, Section iii must be implemented to reduce toxicity before phytoremediation and mangrove replanting takes place.

- Reduction of toxicity and remediation is relatively easier and faster in surface water bodies, therefore as soon as first target levels for CoSC are achieved, rapidly implement a strategy to replace lost fishery resources where applicable, for example, open water aquaculture system introduced by FAO in 2006.

- Fishery resources may be improved in different ways depending on the situation in the community, for example, in creeks, implement re-stocking initiative from less challenged or pristine areas such as in Brass and Akassa.

- Fishermen from affected communities may also be supported by donations of materials and resources to enable them to move further afield in order to continue to harvest fish and help them sustain their income levels, while remediation in their home fishing areas commences.

- Depending on the community needs and abilities, seek alternatives to support income generating/occupational re-adjustment activities with an exit strategy. This is part of the socio-environmental strategy that seeks to integrate communities into plans for remediation when such large spills occur.

Recommendation 4.3.4: Further to the existing sign-off procedures, introduce a final sign-off process within three years post-remediation to ensure that residues of Chemicals of Special Concern have reduced to the required levels and to ensure that there is clear evidence of return of the previous biodiversity and ecosystem function in line with the Panel's Outcome Success Matrix (Annex III, Section iii)

- Introduce two sign-off levels as a means to support the restoration of biodiversity. The first interim sign-off would be based on established target levels especially for CoSCs using Outcome Success Matrix in Annex III, Section iii as a guide.

- Ensure adherence to improved target levels to significantly reduce toxicity levels and promote re-establishment of biodiversity and habitats through successful cycles of phytoremediation (Annex IV, Section v).

- Conduct annual monitoring for a period up to three years to establish ecosystem recovery before internal final sign-off. This means that sites can be closed with established evidence of ecosystem recovery before three years.

4.4 Recommendations for socio-environmental strategy

Credible community stakeholder participation (i.e. partnership with communities) is an essential condition for long-term success and sustainability of oil spill remediation, restoration and rehabilitation efforts.

Evidence from the field suggests that genuine community participation has not been effectively accomplished. A policy of using community–based contractors and/or selective engagement of community personnel does not appear to have created meaningful community stakeholder participation.

The Panels' interviews with community members revealed that these communities regard remediation strategies as being shrouded in mystery with no genuine efforts being made in the past to de-mystify them and make them intelligible to community stakeholders prior to application. The result is that community stakeholders cannot make informed judgements about these technologies and therefore criticize or reject them outright.

Important segments of communities—especially women and youth, who usually drive community development—are hardly consulted, nor is their capacity built, and therefore their enormous potential is not tapped during remediation, restoration and rehabilitation.

Furthermore, in the delivery of corporate social responsibility projects—and evidence of these projects abounds—failure to institute clear exit strategies and enshrine community ownership has led to deterioration, damage or failure, inflicting damage on company reputation, therefore triggering the perception of company neglect and consequent resentment by communities.

Company-engineered sustainable community development activities cannot be divorced from remediation, restoration and rehabilitation efforts. A holistic approach needs to be adopted, such that communities become true business partners. This should be fully discussed in the socio-environmental plan that should be specific to each community.

The following recommendations are made by the Panel:

Recommendation 4.4.1: Recognize and utilize existing community governance structures and the local power and authority hierarchy, for effective community entry, to secure freedom to operate

Although there is some evidence that SPDC is already doing so, there is room for improvement in the manner of interface with the various community groups.

Recommendation 4.4.2: Develop a socio-environmental plan that takes account of the existing governance structures for implementation of remediation activities with a defined exit strategy

Recommendation 4.4.3: Expand existing knowledge and capacity in communities to support new protocols for remediation and ecosystem recovery

For example, management/training of community-based organizations (CBOs) for seedling nurseries needed in phytoremediation; local production of biosurfactants; local production of kenaf sorbent materials for bioremediation; and local production of nutrients by CBOs and government.

Recommendation 4.4.4: Utilize labour-intensive remediation technologies whenever possible and expedient to boost employment opportunities for key community stakeholders (such as youth and women) whose livelihoods are threatened by spills

Recommendation 4.4.5: Boost capacity of target community stakeholders most useful to the processes of ecosystem restoration

Recommendation 4.4.6: Create opportunities for CBOs, NGOs and other organizations to participate in various aspects of implementation of remediation and restoration

Recommendation 4.4.7: Ensure that the ownership process leads to defined exit strategy

Recommendation 4.4.8: Utilize existing Global Memorandum of Understanding (GMOU) arrangements, where possible, as a vehicle to foster effective community participation

4.5 Recommendations for developing a best practice strategy for the biodiversity of the Wider Niger Delta

In view of the extensive footprint of oil operations throughout the Niger Delta, and the fact that oil companies other than SPDC are also operating in this area, it is necessary and expedient to have a strategy to address the conservation and management of biodiversity involving the wider community of oil companies. Some areas are impacted multiple times either due to vandalism or operational overlaps especially where two or more oil companies are operating in close proximity. This makes it imperative that other oil companies are encouraged to participate in the development and implementation of the biodiversity strategy so that the efforts of SPDC will not be exerted in isolation. A common agenda with joint effort, shared responsibility and mutual benefits will promote the success of conservation, management and rehabilitation of biodiversity in the wider Niger Delta.

Further, many of the solutions to biodiversity rehabilitation are beyond the capability of any one actor in the oil industry. The whole industry needs to pool ideas and resources together, and work closely with the regulators, in order to tackle the gigantic problems posed by the widespread oil spillage in the Niger Delta.

Recommendation 4.5.1: Review and update contingency planning and sensitivity mapping including identification of delta-wide biodiversity hotspots

There is a need to review and update approaches to biodiversity conservation on a delta-wide basis. This can be a shared responsibility under the guidance of one organization or with oil companies agreeing to collaborate on a project based on the advice provided by the IUCN protocols for conservation of biodiversity.

The recommendations of IUCN–NDP may provide guidance, while resources needed could be shared amongst the oil companies and government. Such collaboration could be initiated under the auspices of the Oil Producers Trade Section (OPTS) or under the stewardship of IUCN as an impartial coordinator/facilitator. Two areas where joint initiatives are particularly significant are with regards to contingency planning and sensitivity mapping.

There is an immediate need to identify, assess and compile a comprehensive inventory of key biodiversity areas and other sensitive areas in the Niger Delta. An oil industry-wide effort can be achieved by working with IUCN Members in Nigeria with possible support from the Integrated Biodiversity Assessment Tool (IBAT) consortium to which Shell is already a contributor.

Recommendation 4.5.2: Provide capacity building, equipment and material support

The impact of residues or long-term pollution in a sensitive ecosystem such as the Niger Delta is far-reaching and biodiversity recovery requires deep understanding of deltaic systems and how to effectively remediate impacts successfully. This is a holistic venture that needs substantial resources to promote intervention of stakeholders in the long-term processes needed.

Therefore very extensive capacity building and the provision of material support will be required to boost the ability of contractors, community-based organizations and NGOs to support this work. Implementing the recommendations on procedures to speed up response and redefine remediation approaches will also contribute towards this goal.

The importance of such a joint effort is further underscored by the fact that when there is a large-scale oil spill, there should be readily available trained local capacity, materials and resources to contain the spread and recover excess crude irrespective of its source or cause. Ultimately, a slow response to oil spills exacerbates its spread and impact and, by implication, pushes up the costs of clean-up operations. This reinforces the need for the different players in the oil industry to pool their ideas and resources in a joint effort as the financial and other burdens may be very high when borne by an individual company.

Recommendation 4.5.3: Maintain best practice protocols, such as international standards, and protocols for remediation and conservation

Establishment of best practice based on international protocols for conservation, remediation and standards for limiting the effects of pollutants in the environment should be the template for biodiversity rehabilitation and management to be adopted by all oil companies, otherwise impact will be lost if only SPDC drives its own best practice protocols, while others ignore it. Common standards of practice, jointly agreed by the main oil producers, will go a long way to address the present situation where the effectiveness of remediation is patchy across the Niger Delta.

There is also a need for a common strategy to establish monitoring protocols to ensure best practice in the application of monitoring approaches.

Chapter 5

Conclusions

5.1 Making sustainable remediation and rehabilitation work

Having taken into account numerous scientific studies, independent on-the-ground assessments and crucial consultations with a cross-section of stakeholders, the IUCN–NDP recognizes the need to address key underlying factors that would sustain activities for rehabilitation of habitats and biodiversity and ultimately have a positive impact on the recovery of livelihoods previously lost through environmental degradation.

The recommendations of the Panel have taken into consideration the extent of the scale of pollution in the Niger Delta and the various influences both from anthropogenic, climatic and unforeseen factors that all exacerbate pollution and loss of livelihoods in the area. Therefore the recommendations are centred on issues to speed up response to oil spills and take appropriate action to contain, recover and remediate within an acceptable timeframe. The recommendations also call for some internal management restructuring, redefining remediation strategies to address new spills as well as historical and aged spills, and taking action that will bring about ecosystem recovery by essentially boosting Nature's inherent cleanup ability, over a period of time.

The use and application of the recommended remediation techniques must follow a clear set of guidelines as these techniques complement each other and boost efficacy. There is therefore a need to heed the cautions expressed in Annex IV (Sections i and iii) regarding the importance of investigating spill site properties prior to treatment in order to select the most appropriate combination of approaches to achieve the best results. Monitoring of the progress achieved in remediation and rehabilitation of biodiversity and habitats, using the Outcome Success Matrix (Annex III, Section iii), will help identify progress made in eliminating CoSC, which would ultimately improve conditions that support the reappearance of biodiversity.

The challenge essentially is to make these recommendations work through a sustainable remediation plan that engages local communities in remediation strategies, in order to improve the environmental outcomes and strengthen local livelihoods.

The Panel recommends that sites with multiple challenges be selected for the remediation pilot projects that will deploy the full set of recommendations set out in the next chapter. The Panel also recommends that the pilot projects be carried out in collaboration with specialists experienced in various aspects of this type of work, in order to reduce the learning curve and help ensure successful results.

5.2 Local production of bioremediation products

The cost-effectiveness and long-term success of remediation activities will require that stakeholders are motivated to maintain the programme; this is best achieved by ensuring that the remediation produces benefits for the stakeholder groups involved. For SPDC, local production of remediation materials and affordable labour will ensure that costs are relatively low in the long-term. For communities, alternative income opportunities and an ability to participate meaningfully in activities to restore biodiversity and habitats will help address their concerns about being adequately consulted and involved. Capacity building for local universities and institutes is also beneficial to all parties and in the long term will boost local availability of materials and generally open up new opportunities. The application of an exit strategy is a critical factor for stakeholders to make the process viable and sustainable.

The following activities, proposed within the recommendations, will require further development by the Panel in order to support local capacity building and ensure the use of proven scientific approaches to remediation.

Recommendation 5.2.1: Management/training of CBOs for seedling nurseries needed in phytoremediation

Nurseries for various seedlings will be required for success of phytoremediation and rhizoremediation. CBOs will be trained by horticultural specialists to cultivate their own nurseries and sell seedlings for remediation projects in the Niger Delta. In a bid to ensure quality of produced seedlings, a catalogue of certified community nurseries will need to be maintained by oil companies and government.

Recommendation 5.2.2: Local production of biosurfactants

The Panel could support the assessment of capacity and capability of local universities to be trained by international consultants for local production of biosurfactants.

Recommendation 5.2.3: Local production of kenaf sorbent materials for bioremediation

IUCN Members in Nigeria could provide support for CBOs to enable them to develop and implement income-generating projects to produce sorbents (such as booms, pads, etc.) for bioremediation**.**

Recommendation 5.2.4: Local capacity for cultures of native isolates

The Panel could support the assessment of local capacity in Nigerian universities and research institutions to be trained by international consultants for the isolation/culturing of non-pathogenic microbes for inoculation into the environment in combination with other materials such as SpillSorb or directly, where required.

Recommendation 5.2.5: Local production of nutrients by CBOs

The Panel could help build the capacity of CBOs for local production of nutrients to be used in bioremediation.

Recommendation 5.2.6: Applying horticultural and agricultural approaches to remediation

The Panel could seek scientific approaches from institutions such as the National Root Crops Research Institute (NRCRI), Umudike; International Institute for Tropical Agriculture (IITA), Ibadan; Forestry Research Institute of Nigeria (FRIN), Ibadan; and also consult international scientists for phytoremediation and rhizoremediation technologies.

Recommendation 5.2.7: Identification of nesting and breeding sites for key species

IUCN Members in Nigeria could provide management and training for conservation of nesting and breeding sites in the Niger Delta, particularly for key indicator species such as migratory birds, sea turtles, Sclater's guenon and others.

Recommendation 5.2.8: Identification of pristine forest areas

The Panel could provide guidelines for management and training for mangrove forest ecosystem including restoration of degraded forests.

5.3 Wider involvement of oil industry in the biodiversity strategy

The success of recommendations to rehabilitate biodiversity is directly linked to involvement of the wider oil industry in the biodiversity strategy because in some cases, there are operational overlaps amongst oil operators and proximity of receptors to onshore/offshore spills makes this a concern for all.

Therefore, there is a need for collaboration within the oil industry under an umbrella institution to facilitate better and quicker access to modern scientific technology, materials and equipment to respond to major oil spills within 48 hours. For offshore sites especially, produced water is appearing to be an increasing concern, showing up residues for PAHs and its intermediaries, which will have significant impacts on marine life. A number of international oil companies are operating offshore and since there is no easy way to delineate or apportion responsibilities in such offshore situations, this could be a project for the wider involvement of oil companies operating in Nigerian waters.

This ethos cuts across boundaries of the oil industry and also calls for shared responsibility for better trained contractors and CBOs delivering similar projects for remediation in the Niger Delta. To make this feasible, IUCN and the Nigerian government, working with other stakeholders, could set up the vehicle to initiate this recommendation.

References

Abam T.K.S. (2001). Regional Hydrological Perspectives in the Niger Delta. *Hydrological Sciences Journal* Vol. 46, 14 pp.

Abu Gideon O. and Atu Nancy D. (2008). An Investigation of Oxygen Limitation in Microcosm Models in the Bioremediation of a Typical Niger Delta Soil Ecosystem Impacted with Crude Oil. *Journal of Applied Science and Environmental Management* Vol. 12 issue 1 pp. 13–22.

Agbogidi Mary O., and Ufuoka Albert U. (2000). Biodiversity Conservation and Poverty Alleviation in the Niger Delta Area of Nigeria. *Agriculturae Conspectus Scientificus* Vol. 71, No.3, pp. 103–110.

Adenipekun C. O. and Fasidi I. O. (2005). “Bioremediation of Oil-Polluted Soil by *Lentinus subnudus*, a Nigerian White-Rot Fungus”. *African Journal of Biotechnology* Vol. 4, No.8, pp. 796–798.

Agbogidi O. M., Edema N. E. and Agboye I. (2011). 10 Year Evaluation of African Bread Fount (*Treculia* Africana Decene) for Bioremediation in Soils Impacted with Crude Oil. *International Journal of Science and Nature* Vol. 2, No. 3, pp. 461–466.

Agbogidi O. M., Dolor E. D., Okechukwu E. M. (2006). Evacuation of *Tectona grandis* (Linn) and Gmelina Arboren (Roxb) for Phytoremediation in Crude Oil Contaminated Soils. *Agriculturae Conspectus Scientificus* Vol. 72, No. 2, pp. 149–152.

Banat, I.M. et al. (2000). Potential Commercial Applications of Microbial Surfactants . Applied *Environmental Microbiology* Vol. 53, pp. 495–508.

Blench R. and Dendo M. (2007). *Mammals of the Niger Delta*, *Nigeria*. A compilation of articles by Powell C.B and Williamson K. on mammals of the Niger Delta. Kay Williamson Education foundation, Cambridge , UK.

Bishop D.F. et.al. (1968). “Hydrogen Peroxide Catalytic Oxidation of Refractory Organics in Municipal Waste Waters”. *Industrial and Engineering Chemistry Process Design & Development* Vol.7, pp. 110–117.

Cline G.R., Reid P.C.P., Powell P. E., and Szaniszlo P.J. (1984). Effects of a Hydroxymate Siderphore on Iron Absorbtion by Sunflower and Sorghum. *Plant Physiology* Vol. 76 pp. 36–39.

Dahrazma, B., and Mulligan, C. N. (2007). Investigation of the Removal of Heavy Metals from Sediments Using Rhamnolipid in a Continuous Flow Configuration, *Chemosphere* Vol 24, pp. 928–935.

Das, K., and Mukherjee, A. K. (2007). Comparision of Lipopeptide Biosurfactants Production by *Bacillus subtilis* Strains in Submerged and Solid State Fermentation Systems Using a Cheap Carbon Source: Some Industrial Applications of Biosurfactants. *Process Biochem*istry. Vol. 42, pp. 1191–1199.

Das, K., and Mukherjee, A. K. (2007). Crude Petroleum-Oil Biodegradation Efficiency of *Baccillus subtilis* and *Pseudomonas aeruginosa* Strains Isolated from a Petroleum-Oil Contaminated Soil from North-East India. *Bioresource Technology* Vol. 198, pp 1339.

Das, P., Mukherjee S., and Sen, R. (2009). Biosurfactant of Marine Origin Exhibiting Heavy Metal Remediation Properties, *Bioresource Technology* Vol 100, pp. 4887–4890.

Dickson U.J. and Udoessien E. I. (2012). Physicochemical studies of Nigeria's Crude Blends. *Petroleum and Coal* 54 (3) 243–251.

Diab E. A. (2008). Phytoremediation of Oil Contaminated Desert Soil Using the Rhizosphere Effect. *Global Journal of Environmental Research* Vol. 2, No. 2, pp. 66–73.

Dipu, S., Anju, A.K., Salom, G., and Thanga, V. (2011). "Potential Application of Macrophytes Used in Phytoremediation" *World Applied Sciences Journal* Vol. 13, No. 3, pp. 482–486.

Doong, R. A. (1998). Surfactant-Enhanced Remediation of Cadmium Contaminated Soils. *Water Science Technology* Vol. 37, pp. 65–71.

Edwards K. R., Lepo J. E., and Lewis M. A. (2003). Toxicity comparison of biosurfactants and synthetic surfactants used in oil spill remediation to two estuarine species. *Marine Pollution Bulletin* Vol. 46, pp. 1309–1316.

Emoyan, O.O., Akpoborie, I.A., and Akporhonor, E.E. (2008). The Oil and Gas Industry and the Niger Delta: Implications for the Environment. *Journal of Applied Sciences and Environmental Management* Vol. 12 (3) pp. 29–37.

Gerson, O. F. and Zajic, J. E. (1978). Surfactant Production from Hydrocarbons by *Corynebacterium lepus sp. nov and Pseudomonas asphaltenicus, sp. nov Dev. Industrial Microbiology* Vol. 19, pp. 577–599.

Greenberg, R., T. Andrews, P. Kakarla, and R. Watts. (1998). "In Situ Fenton-Like Oxidation of Volatile Organics: Laboratory, Pilot, and Full-Scale Demonstrations," *Remediation* **8**(2): 29–42.

Heider J., Spormann A. M. , Beller H. R. , Widdel F. (1999). Anaerobic Bacterial Metabolism of Hydrocarbons. FEMS Microbiology Reviews 22 pp. 459–473.

Interstate Technology and Regulatory Council (ITRC) (2005). Technical and Regulatory Guidance for in situ chemical oxidation of contaminated soil and ground water second edition. Washington DC.

Kathi S. And Khan A. B. (2011). "Phytoremediation Approaches to PAH Contaminate Soil". *Indian Journal of Science and Technology* Vol. 4, No. 1.

Kanaly R. A. and Harayama S. (2000). Biodegradation of high Molecular Weight Polycyclic Aromatic Hydrocarbons by Bacteria. *Journal of Bacteriology*, Apr 2000, pp. 2059–2067.

Karigar C. S. and Rao S. (2011). Role of Microbial Enzymes in the Bioremediation of Polluttants: A Review. SAGE-Hindawi Access to Research. Vol 2011, article ID 805187, 11 pages.

Kosaric, N. (2001). Biosurfactants and their application for soil bioremediation, *Food Technology and Biotechnology* Vol. 39, pp. 295–304.

Javaheri M., Jenneman G.E., McInerney, M.J. and Knapp R. M. (1985). Anaerobic Production of a Biosurfactant by *Bacillus licheniformis* JF-2. *Applied and Environmental Microbiology* pp. 698–700.

Mohan P. K., Nakha G. and Yankful I. K. (2006). “Biodegradation of surfactants under aerobic, anoxic and anaerobic conditions” *Journal of Environmental Engineering* Vol. 132, No. 2, pp. 279–283.

Ndimele P. E. (2010). A Review on the Phytoremiediation of Petroleum Hydrocarbon. *Pakistan Journal of Biological Sciences* Vol. 13, No. 15, pp. 715–722.

Njoku, K.I., Akinola, M.O., and Oboh B.O. (2009). Phytoremediation of Crude Oil Contamination Soil, The Effect of Growth of Glycline Max on the Physico-Chemistry and Crude Oil Contents of Soil. *Nature and Science* Vol. 7, No. 10 (2012).

Njoku, K. L., Oboh, B. O., Akinola, M. O. And Ajasa, A. (2012). “Comparative Effects of *Abelmoschus esculentus* (L) *Moench* (Okro) and *Corchorus olitorius* L. (Jew Mallow) on Soil Contaminated with Mixture of Petroleum Products” *Research Journals of Environmental and Earth Sciences* Vol. 4, No. 4, pp. 413–418.

Obire O., Anywanwu E. C. and Okigbo R. N. (2008). “Saprophytic and Crude Oil degrading Fungi from Cow Dung and Poultry Droppings as Bioremediating Agents”. *Journal of Agriculture Technology* Vol. 4, No. 2, pp. 81–89.

Oil &Gas Producers (2005). Fate and effects of naturally occurring substances in produced water on the marine environment. International Association of Oil & Gas Producers, London, UK, Report No 364. 36 pp.

Pampanin M. Daniela, Sydnes O. Magne (2013). Polycyclic Aromatic Hydrocarbons a Constituent of Petroleum: Presence and Influence in the Aquatic Environment.

Perfumo, A., Smyth, T. J. P., Marchant, R., and Banat, I. M. (2001). Production and Roles of Biosurfactants and Bioemulsifiers in Accessing Hydrophobic Substrates. *Handbook of Hydrocarbon and Lipid Microbiology* Vol. 47, pp. 1502–1511.

Peixoto R. S. , Vermelho A.B., Rosado A.S. (2011). Petroleum Degrading enzymes: Bioremediation and New Prospects . SAGE-Hindawi Access to Research. Vol 2011, article ID 475193, 7 pages.

Phil-Eze P. O. and Okoro I. C. (2008). Sustainable Biodiversity Conservation in the Niger Delta: A Practical Approach to Conservation Site Selection. *Biodiversity and Conservation* No. 118, Issue 5, pp. 1247–1257.

Mohan P. K.; Nakla G. and Yankful E.K. (2005). Biodegradability of Surfactants under Aerobic, Anoxic and Anaerobic Conditions. Journal of Environmental Engineering. Vol. 132, No. 2, pp. 279–283.

Sheng, X.,He, L. Wang, Q., Ye, H., and Jang C. (2008). Effects of Inoculation of Biosurfactant-producing Bacillus sp. J119 on Plant Growth and Cadmium Uptake in a Cadmium-amended Soil. *Journal for Hazardous Materials* Vol. 155, pp. 17–22.

Tanee, F.B.; and Love, A. A. (2009). Effectiveness of *Vigna unguiculata* as a Phytoremediation Plant in the Remediation of Crude Oil Polluted Soil for Cassava (*Manihot esculenta*: Crantz) Cultivation. *Journal of Applied Environmental Management*. Vol. 13, No. 1, pp. 43–47.

Thavasi, R., S., Jayalakshmi, T., Balasubramanian., and Ibrahim, M. B. (2007). Production and Characterization of a Glycolipid Biosurfactant from *Bacillus megaterium* Using Economically Cheaper Sources. *World Journal of Microbiology and Biotechnology* Vol. 24, pp. 917–925.

ThisDay Newspapers, (6th March, 2013). Chalker: Nigeria's Economic Growth Threatened by Terrorism, oil Theft . Leaders and Company, Limited vol. 18. No 6525 pp 8–9.

USEPA (1991). Standard Default Exposure factors. OSWER Directive 9285.6-03.

USEPA (1993). Provisional Guidelines for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons EPA/600/R-93/089 28 pages.

USEPA (1998). Field Applications of In-Situ Remediation Technologies Chemical oxidation. EPA 542-R-98-008.

USEPA (2002). A Review of the reference dose and reference concentration processes. Risk Assessment Forum pp 3–33.

USEPA (2009). Integrated Risk Information System (IRIS) for Benzo(a)pyrene BAP CASRN 50-32-8.

USEPA (2009). Integrated Risk Information System (IRIS) for Dibenz(a,h) anthracene. CASRN 50-70-3.

Vicente F., Rosas J.M., Santos A., and Romero A. (2011). Improvement of Soil Remediation by Using stabilizers and Chelating afgents in Fenton-like Process. *Chemical Engineering Journal* pp 689–697.

Wang, S., and Mulligan, C. N. (2004). "Rhamnolipid Foam Enhanced Remediation of Cadmuim and Nickel Contaminated Soil". *Water, Air and Soil Pollution* Vol. 157, pp. 315–330.

White P. M., Wolf D. C., Thoma G. J. And Reynolds C. (2006). "Phytoremediation of Alkylated Polycyclic Aromatic Hydrocarbons in a Crude Oil-Contaminated Soil". *Water Air and Soil Pollution* Vol. 169, pp. 207–220.

WHO/IPCS (1998). Environmental Health Criteria 202: Selected Non-Heterocyclic Polycyclic Aromatic Hydrocarbon. International Program on Chemical Safety, United Nations Environment Programme, World Health Organization. Geneva.

Wuana, R.A., and Okieimen, F.E. (2010). Phytoremediation Potential of Maize (*Zea mays* L.) A Review. *African Journal of General Agriculture* Vol. 6, No 4, pp. 1595–6984.

Bibliography

Academy of Sciences and Arts of Bosnia and Herzegovina (2012). Biodiversity – Theoretical and Practical Aspects. Proceedings No. 22 Biodiversity of Macrophyto and Phytoremediation of Heavy Metals Accummulation in the Aquatic Ecosystems pp. 187–207.

Agbontalon E. A. (2007). "Phytoremediation: An Environmentally Sound Technology for Pollution Prevention, Control and Remediation in Developing Countries". *Educational Research and Review* Vol. 2, No. 7, pp. 151–156.

Aghalino S. O. and Eyinla B. (2009). Oil Exploitation and Marine Pollution: Evidence from the Niger Delta, Nigeria. *Journal of Human Ecology* Vol 28, No. 3, pp. 177–182.

Amnesty Internal (2009). Nigeria: Petroleum, Pollution and Poverty in the Niger Delta. Amnesty International London: UK.

Anandaray B. and Thivakaran P. (2010). Isolation and Production of Biosurfactant Producing Organism from Oil Spilled Soil. *Biological Science Technology* Vol 1, No. 3pp. 120–126.

Aparna, A., Srinikethan, G., and Hedge S. (2011). Effect of Addition of Biosurfactant Produced by *Pseudomonas sps*. on Biodegradation of Crude Oil. Second International Conference on Environmental Science and Technology irt BEE Vol. 6.

Banat, I.M., Franzetti, A., Gandolfi, I., Bestetti, G., Martinotti, M. G., Francchia, L., Smyth, T. J. and Merchant R. (2010). Microbial Biosurfactants Production, Applications and Future Potential *Applied Microbiology Biotechnology* Vol. 87, pp. 427–444.

Bayomi R and El-Nagar A. Y. (2009). Safe Control Methods of Petroleum Crude Oil Pollution in the Mangrove Forest of the Egyptian Red Sea Coast. Journal of Applied Sciences Research Vol. 5, No. 12, pp. 2435–2447.

Bicca, F. G., Fleck, l. C. and Anjub, M. A. (1999). Production of Biosurfactant by Hydrocarbon Degrading *Rhodococcus rubber* and *Rhodococcus erythropolis Revista de Microbiologica* Vol. 30, pp. 231–238.

Bidoia E. D., Montagnolli R. N., Lopes P.R.M., Chris D. C. and Williey N. (2002). Implementing Phytoremediation of Petroleum Hydrocarbons. *Methods in Biotechnology* Vol. 23.

Cipinyte V., Grigiskis S., Sapokite D. and Baskys E. (2011). Production of Biosurfactants by *Arthrobacter* Sp. N3, Hydrocarbon Degrading Bacterium. Environment Technology Resources, Proceedings of the 8th International Scientific and Practical Conference Vol. 1.

Uyialue, E. and Agho, M. (2007). *Coping with Climate Change and Environmental Degradation in the Niger*. Community Research and Development Centre Uselu, Edo State, Nigeria.

Corn, L.M. and Copeland, C. (2010). The Deep Water Horizon Oil Spill: Coastal Wetland and Wildlife Impacts and Response. Congressional Research Service, CRS Report for Congress 7 – 5700.

Dakpitchareon A., Dotivejkal K., Kan Janavas P and Areekit S. (2008). Biodiversity of Thermotolerant *Bacillus sp.* Producing Biosurfactants, Biocatalysts, and Antimicrobial Agents. *Science Asia* Vol. 34, pp. 424–431.

Das, P., Mukherjeee, S., and Sen, R. (2008). Improved Bioavailability and Biodegradation of a Model Polycyclic aromatic Hydrocarbon by a Biosurfactant Producing Bacterium of Marine Origin. *Chemosphere* Vol. 72, pp. 1229–1234.

Desai, J. D., and Banat I. M. (1997). Microbial Production of Surfactants and their Commercial Potential *Mirobiology Molecular Biology* Vol. 61, pp. 47–64.

Edward R. K., Lepo J. E. and Lewis A. M. (2003). "Toxicity Comparison of Biosurfactants and Synthetic Surfactants used in Oil Spill Remediation to Two Estuarine Species". . *Marine Pollution Bulletin* 46 pp. 1309–1316.

Efe S. I. and Okpali A. E. (2012). Management of Petroleum Impacted Soil with Phytoremediation and Soil Amendments in Ekpan, Delta State, Nigeria. Journal of Environmental Protection. Vol. 3, pp. 386–393.

EPA (1998). A Citizen's Guide to Phytoremediation. United States Environmental Protections Agency. EPA 542 F – 98 – 011.

EPA (2008) Enhanced Aerobic Bioremediation. United States Environmental Protection Agency Chapter XII, pp. 1–73.

EU (2000). "Management of contaminated sites in Western Europe". Topic Report 13/1999, European Environmental Agency.

Erftemeijer, P.L.A. and R. R. Lewis, R.R. (2000). "Planting mangroves on intertidal mudflats: habitat restoration or habitat conversion?" Proceedings of the ECOTONE VIII Seminar Enhancing Coastal Ecosystems Restoration for the 21st Century, Bangkok: Royal Forest Department of Thailand.

European Commission Joint Research Center-Institute for Reference Materials and Measurement (2010). RC Technical Notes: Polycyclic Aromatic Hydrocarbons (PAH). Factsheets. 3rd Edition, Compiled by Lerda D. Brussels, Belgium.

Federal Republic of Nigeria (1999). *Niger Delta Regional Development Master Plan*, Niger Delta Region Land and People, Abuja, Nigeria.

Field, C.D. (1998). "Rehabilitation of Mangrove Ecosystems: An Overview". *Marine Pollution Bulletin* Vol. 37, No. 8–12. Pp. 383–392.

Franzetti, A., Gandolfi I. Bestetti G. and Banat I. M. (2010). Biosurfactant and Bioremediation, Successes and Failures". *Trends in Bioremediation and Phytoremediation.* pp. 145–156.

Franzetti, A., Gandolfi, I., Bestetti, G., Smyth, T. J., and Banat, I. M. (2010). Productions and Applications of Trehalose Lipid Biosurfactants. *European Journal of Lipid Science Technology* Vol. 112, pp. 617–627.

Gattenlöhner, U., Lampert S. and Wunderlich, K. (2007). "Mangrove Rehabilitation Guidebook". Global Nature Fund, GNF 04/2007.

Gao Y. Z., Ling W. T. and Wong M. A. (2006). Plant Accelerated Dissipation of Phenathrene and Pyrene from Water in the Presence of a Non-Ionic-Surfactant. *Chemosphere* Vol. 63 pp. 1560–1567.

Ghosh M. and Singh S. P. (2005). A Review on Phytoremediation of Heavy Metals and Utilization of ts By-Products. *Applied Ecology and Environmental Resources*. Vol. 3, No. 1 pp. 1–8.

Government of Alberta (2001). *Alberta Soil and Water Quality Guidelines for hydrocarbons.* Alberta Canada.

Government of Alberta, Canada (2010). *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* ISBN: 978-0-7785-9947-0 Alberta, Canada.

Government of Alberta, Canada (2010). *Alberta Tier 2 Soil and Groundwater Remediation Guidelines* ISBN: 978-0-7785-9949-4 Alberta, Canada.

Government of Nunavut, Dept of Environment, Canada (2009). *Environmental Guidelines for Contaminated Site Remediation,* Nunavut, Canada.

Canwenberghe, L. G. and Roote, D. G. (1998). Insitu Bioremediation. Grand-Water Remediation Technology Analysis Centre, Pittsburgh, USA.

Colwell, R.R. (1980). Toxic Effects of Pollutants on Microorganisms, pp. 275–294. Department of Microbiology, University of Maryland, USA.

Frick C. M., Farrell R. E. and Germida J. J. (1999). *Assessment of Phytoremediation as an in-situ technique for cleaning oil contaminated sites*. Petroleum Technology Alliance of Canada, Saskatoon, Canada.

Herman, D. C., Artiola, J. F., and Miller, R. M. (1995). "Removal of Cadmium, Lead, and Zinc from Soil by a Rhamnolipid Biosurfactant*". Environmental Science Technology* Vol. 29, pp. 2280–2285.

Hoefler C. B., Gorzelnik R. V., Yang J. Y. Hendricks N., Dorrestein P.C. and Straight P. D. (2012). "Enzymatic Resistance to the Lipopeptide Surfaction as Identified Through Imaging Mass Spectrometry of Bacterial Competition".*Proceedings National Academy of Sciences* USA Vol. 109(32): 13082–13087.

Holman H. N., Nieman K., Sorensen L. D., Miller C. D., Martin C. M., Borch T., McKinney W. R. And Sims R. C. (2002). "Catalysis of PAH Biodegradation by Humic Acid Shown in Synchrotron Infrared Studies". *Environmental Science and Technology*. Vol. 36 No. 6, pp. 1276–1280.

International Finance Cooperation (2006). External Monitoring of the Chad-Cameroon Pipeline Project Lessons of Experience. No. 1, pp. 1– 6. IFC, World Bank Group, Washington D.C., USA.

IUCN (2008). "Mangroves", Coastal Ecosystems Series. IUCN, Gland, Switzerland.

Jackson, L. L., N. Lopoukhine and Hillyard, D. (1995). ‘Ecological restoration: a definition and comments. *Restoration Ecology* 3(2): 71–75.

Juwarkar A. A., Nair A., Dubey K. V., Singh S. K and Devotta S. (2007). Biosurfactant Technology for Remediation of Cadmium and Lead Contaminated Soils. *Chemosphere* Vol. 68, pp. 1996–2002.

Kosaric, N., (1992). “Biosurfactants in Industry”. *Pure Appl. Chem*. Vol. 64, pp. 1731–1737.

Leo K. and E. M. Levy (1989). Enhancement of the Natural Biodegradation of Condensate and Crude Oil on Beaches of Atlantic Canada. Proceedings of the 1989 Oil Spill Conference, American Petroleum Institute, Washington D.C. pp. 479–486.

Lewis, R.R. (1992). “Coastal habitat restoration as a fishery management tool”, in Stroud, R.H. (Ed.), *Stemming the Tide of Coastal Fish Habitat Loss*. Savannah: National Coalition for Marine Conservation, Inc.

Lewis, R. R. (2000). “*Ecologically based goal setting in mangrove forest and tidal marsh restoration in Florida*”, *Ecological Engineering* 15(3–4): 191–198.

Lewis, R.R. and M.J. Marshall, M.J. (1997). “*Principles of successful restoration of shrimp aquaculture ponds back to mangrove forest*”, Programa/resumes de Marcuba ‘97*,* September 15/20, Palacio de Convenciones de La Habana, Cuba. Page 126 (abstract).

Linden O. and Husain, T., (2002). “Impact of wars: The Gulf War 1990–91”. In Kahn, N.Y. and Munawar, M. (Eds). *The Gulf Ecosystem: Health and Sustainability*. Backhuys Publ. Linden. 279–290.

Linden, O. and Moffat, D. (1995). *Defining an Environmental Development Strategy for the Niger Delta,* Vols 1 and 2. World Bank, Washington, DC, USA.

Maier, R. M. and Soberon-Chavez, G. (2000). *Pseudomonas aeruginosa* Rhamnolipids: Biosynthesis and Potential Applications”. *Appl Microbiol. Biotechnol.* Vol. 54, pp. 625–633.

Millioli V. S., Servulo E-L. C., Sobral L. G. S. and De Carvalho (2009). “Bioremediation of Crude Oil-Bearing Soil: Evaluating the Effect of Rhamnolipid Additon to Soil Toxicity and Crude Oil Biodegradation Efficiency”. *Global Nest Journal*. Vol. 11, No. 2, pp. 181–188.

Mmom P.C. and Arokoyu S. (2010). Mangrove Forest Depletion, Biodiversity Loss and Traditional Resources Management Practices in the Niger Delta, Nigeria. *Research Journal of Applied Sciences, Engineering and Technology* Vol. 2, No. 1, pp. 28–34.

Mmom P.C. and Decker T. (2010). Assessing the effectiveness of Land Farming in the Remediation of Hydrocarbon Polluted Soils in the Niger Delta, Nigeria Research Journal of Applied Sciences, Engineering and Technology. Vol. 2, No. 7 pp. 654–660.

Nguyen T. T., Youssef N. H., McInerney M. J., Sabatini D. A. (2008). “Rhamnolipid Biosurfactant Mixtures for Environmental Remediation” *Water Resources* Vol. 42, pp. 1735–1743.

Ogboghodo I. A., Iruaga E. K. Osemota O. L. and Chokor J. U. (2004). "An Assessment of the Effects of Crude Oil Pollution on Soil Properties, Germination and Growth of Maize (*Zea Mays*) Using Two Crude Oil Types – Forcados Light and Escravos Light. *Environmental Monitoring Assessment* Vol. 96 pp. 143–152.

Ogbonna D. N., Iwegbue C. M. A., Sokari T. G. and Akoko I. O. (2007). "Effect of Bioremediation on the Growth of Okro (*Abelmoshus esculentus*) in the Niger Delta Soils". Environmentalist No. 27 pp. 303–309.

Oil &Gas Producers (2005). Fate and effects of naturally occurring substances in produced water on the marine environment. International Association of Oil & Gas Producers, London, UK,Report No 364. 36 p.

Okoliegbe, I.N. and Agarry, O.O. (2009). "Application of Microbial Surfactant" (A Review). *Scholarly Journals of Biotechnology*. Vol. 1, No. 1, pp. 15–23.

Okoro C., Agrawal A. And Callbeck C. (2010). "Isolation and Characterization of Thermotolerant Aerobic Bacteria that Produce Biosurfactans and Degrade Petroleum Hydrocarbons from Produced Water Discharge Point". *Nature and Science* Vol. 10, No. 8.

Organisation for Economic Cooperation and Development (1995). *OECD Series on the Test Guidelines Programmed: Detailed Review Paper on the Biodegradability Testing*. Environmental Monograph No. 98. OECD, Paris, France.

Orji F. A., Ibiene A. A. and Ugbogu O. C. (2010). "Petroleum Hydrocarbon Pollution of Mangrove Swamps: The Promises of Remediation by Enhanced Natural Attenuation". *American Journal of Agriculture and Biological Sciences* Vol. 7, No. 2, pp. 207 216.

Pacwa-Plociniczak M. Plaza G. A., Diotrowska-Seget Z. And Cameotra S. S. (2011). Environmental Applications of Biosurfactants: Recent Advances". International Journal of Molecular Sciences Vol. 12, pp. 633–654.

Peltola R., Salonen – Sakinoja M., Romantschuk M. Koivula T, Hagoblom M. Jorgensen K. D. and Harms H. (2008). *Bioavailability Aspects of Hydrophobic Contaminants and Degradation in Soil*. University of Helsinki, Faculty of Ecology and Environmental Sciences, Dept of Allied Chemistry and Microbiology. Helsinki, Finland.

Prakash B. And Irfan M. "*Pseudomonas aeruginosa* is Present in Crude Oil Contaminated Sites of Barmer Region (India)". *Journal for Bioremediation and Biodegradation* Vol. 2, p. 129.

Priya T. and Usharami G. (2009). "Comparative Study for Biosurfactant Production by using *Bacillus Subtilis* and *Pseudomonas Aeroginosa*" *Botany Research Centre* Vol. 2, No 4, pp. 284–287.

Radwan S. S., Dashti N. and El-Nemr I. M. (2005). "Enhancing Growth of *Vicia Fabia* Plants by Microbial Innoculation to Improve Their Phytoremediation Potential for Oily Desert Areas. International Journal Phytoremediation" Vol. 1, No. 7, pp. 19–32.

Rahman, K. S. M., Rahman, T. J., Kourkoutas, Y., Petsas I., Marchant, R., and Banat I. M. (2003). "Bioremediation of n-alkane Petroleum Sludge Using Bacterial Consortium Amended with Rhamnolipid and Micronutrients". *Bioresources and Technology* Vol. 90, pp. 150–168.

Rosenberg, E. and Ron E. Z. (1999). "High and Low-Molecular-Mass Microbial Surfactants". *Applied Microbiology and Biotechnoly* Vol. 52, pp. 154–162.

Salihu A. Abuldukadir I. and Al Mustapha M. N. (2009). "An investigation fro Potential Development on Biosurfactants". *Biotechnology and Molecular Biology Reviews* Vol. 3, No. 5 pp. 111–117.

Saenger, P. and Siddiqi, N.A. (1993). "*Land from the sea: the mangrove afforestation programme of Bangladesh*", *Ocean and Coastal Management* Vol. 20: 23–29.

Sapute S.K., Banat I. M., Dhakephalkar P. K., Banpurkar A. Chopade B. A. (2010). 'Biosurfactants, Bioemulsifiers and Exopolysaccharides from Marine Microorganisms''. *Biotechnology Advances* Vol. 28, pp. 436–450.

Seddon S. (2004). "*Going with the flow: Facilitating seagrass rehabilitation*". *Ecological Management & Restoration*, Vol. 5, No. 3 pp. 167–176.

Shaligram S.S and Singhal R.S., (2010.). Surfactants: A Review on Biosysnthesis, Fermentation, Purification and Applications" *Food Technology and Biotechnology* Vol. 2, pp. 199–134.

Shell Petroleum Development Company of Nigeria (2004).*Niger Delta Environmental Survey (NDES*) Phase Two Report. SPDC, Port Harcourt, Nigeria.

Seydlova G. Cabala R. And Svobodova J. (2010). *Surfactin–Novel Solutions for Global Issues*. pp 305–30. See www.intechopen.

Shell Petroleum Development Company of Nigeria (2011). Risk Management System version 3. SPDC, Port Harcourt, Nigeria.

Sifour, M., Al-Jilawi M. H. and Aziz, G. M. (2007). "Emulsification Properties of Biosurfactant Produce from *Pseudomonas aeruginosa RB 28". Pak. Biol Science* Vol. 11, pp. 1331–1335.

Sitoluy M. Z., Rashad M. M., Sharobeem S. F., Mahmoud A. E., Nooman M, and Al-kashef A. S. (2010). "Bioconversion of Soy Processing Waste for Production of Biosurfactants" *African Journal of Microbiology Research* Vol. 4, No. 24, pp. 2811–2821.

Smiths M. J., Flowers T. H., Duncan H. J. and Alder J. (2006). Effect of polycyclic aromatic hydrocarbons on germination and subsequent growths of grasses and legumes in freshly contaminated soil and soil with aged PAHs residues, *Environmental Pollution* Vol. 141, pp. 529–525.

Solvary Interox (2001). *Hydrogen Peroxide in Soil and Ground Water Remediation* Revised Version.

Suthar, H., Hingurao, K., Desai, A., and Nerurkar, A., (2008). "Evaluation of Bioemulsifier Mediated Microbial Enhanced Oil Recovery Using Sand Pack Colum". *J. Microbiol. Methods* Vol. 75, pp. 225–230.

Tuleva B., Christova N., Jordanov B., Nikolova Damyanova B. and Petrov P. (2005). Napthalene Degradation and Biosurfactant Activity by *Bacillus Cerens* 28BN. Z. Naturtorch 60c pp. 577–582.

United Nations Development Programme (2006). *Niger Delta Human Development Report.* UNDP, Abuja, Nigeria.

United Nations Environment Programme (2011). *An Environmental Assessment of Ogoniland.* UNEP, Nairobi, Kenya.

Millioli, V. S., Servulo, E-L. C., Sobral, L. G. S. and De Carvalho D. D. (2009). Bioremediation of Crude Oil-Bearing Soil: Evaluating the Effect of Rhamnolipid Addition to Soil Toxicity and to Crude Oil Biodegradation Efficiency. *Global Nest Journal*, Vol. 11, No. 2, pp. 181–188.

Whang, L. M. ; Liu, P. W. G., Ma, C. C., Cheng S. S. (2008). "Application of Biosurfactant, Rhamnolipid, and Surfactin for Enhanced Biodegradation of Diesel-Contaminated Water and Soil". *Journal of Ministry of Economic Affairs* 92-EC-17-A10-SI 0013 and 93-EC-17-A10-SI 0013, pp. 155–163.

Xia H.L. and Yan Z Chi and Cheng W. W. (2009). Enhancing Plant Uptake of Plychlorinated Biphenyls and Cadimium using Tea Saponin. *Journal of Bioresource Technology* Vol. 100, No. 2 pp. 4649–4653.

Zhu X., Venosa A., Suidan M and Lee K. (2004). Guidelines for Bioremediation of Oil Contaminated Salt Marches. Journal of USEPA R-04/074. USEPA, USA.

INTERNATIONAL UNION
FOR CONSERVATION OF NATURE

WORLD HEADQUARTERS
Rue Mauverney 28
1196 Gland, Switzerland
Tel +41 22 999 0000
Fax +41 22 999 0002
www.iucn.org