Ecological Indicators for the Industrial Corridor in the Gamba Complex of Protected Areas: A Zone of High Biodiversity Value and Oil Exploration in Southwest Gabon

Francisco DALLMEIER[1], Alfonso ALONSO[1], Patrick CAMPBELL[1], Michelle E. LEE[2], Ralph BUIJ[2] and Olivier S.G. PAUWELS[2, 3]

1 Introduction

The Gamba Complex of Protected Areas is an 11,320 km^2 preserve on the southwest coast of Gabon that supports significant habitat and species diversity, as well as the country's largest onshore oil reserves (see map page xxxii). The Complex has been designated as a series of connected faunal reserves and hunting areas since the 1950s to protect zones of exceptionally-rich wildlife diversity. Today, two national parks frame the east and west of the Gamba Complex: Moukalaba-Doudou (4500 km^2), special for mountains rich in "refuge" biodiversity and great apes; and Loango (1550 km^2), known for its terrestrial-marine megafauna, intricate habitat mosaics, and ecotourism potential. As national parks these are IUCN Category II protected areas (IUCN 1994). Each park bears a minimum 5 km buffer zone.

Between the parks lie the IUCN Category IV hunting domains of Iguéla, Ngové-Ndogo, and Setté Cama, also known as the Industrial Corridor (3585 km^2) due to oil and logging activities. Logging – a pillar of Gabon's economy – has occurred in the area since roughly the 1920s, and continues today along the northern edge of the protected area complex, with one operational base located inside Moukalaba-Doudou National Park. The area has been prospected for oil for over 40 years, and today's eight exploration permits cover 6848 km^2, with one of those areas within Loango National Park. The Complex's ten exploitation permits are run by four operators, and are responsible for much of Gabon's oil-based economy. Oil reserves are believed to be in decline (Trebaol and Chaillol 2002). The Industrial Corridor supports rich biodiversity. The Gamba Complex is part of a larger ecological landscape known as the Gamba-Conckouati Landscape, which is currently proposed as a World Heritage site. Two of Gabon's three Ramsar Wetlands of International Importance sites are in the Gamba Complex – Petit Loango and Setté Cama.

Research activities of the Gabon Biodiversity Program, a partnership between the Smithsonian Institution, Shell Gabon and the Shell Foundation, have documented that the Industrial Corridor in the Gamba Complex of Protected Areas is one of the richest lowland rainforest sites in terms of biodiversity in Central Africa (Lee *et al*. this volume; see Fig. 1, page xxx). In the corridor scientists have recorded the country's greatest species richness for reptiles (Pauwels *et al*. this volume) and amphibians (Burger *et al*. this volume), as well as large numbers of plant species (Campbell *et al*. this volume; Stevart and Droissart, this volume), insect (Basset *et al.* 2004), bird (Angehr *et al*. this volume), small mammal (O'Brien *et al*. this volume; Rodriguez *et al*. this volume; Primus *et al*. this volume), and fish species (Mamonekene *et al*. this volume). Populations of nesting sea turtles (Billes *et al*. this volume) and large mammal species of global conservation concern are significant for the region (Rosenbaum and Collins this volume, Lahm and Tezi this volume, Boddicker this volume). These include the African forest elephant (*Loxodonta cyclotis)*, western gorilla (*Gorilla gorilla gorilla*), chimpanzee (*Pan troglodytes)*, African forest buffalo (*Syncerus caffer nana*), hippopotamus (*Hippopotamus amphibius*), sitatunga (*Tragelaphus spekii gratus*), long-snouted crocodile (*Crocodylus cataphractus*), Nile crocodile (*Crocodylus niloticus*), dwarf crocodile (*Osteolaemus tetraspis*), humpback

[1] Monitoring and Assessment of Biodiversity Program, National Zoological Park, Smithsonian Institution, 1100 Jefferson Drive SW #3123, Washington DC 20560-0705, USA. Emails: fdallmeier@si.edu, aalonso@si.edu, pcampbell@si.edu

[2] Monitoring and Assessment of Biodiversity Program, National Zoological Park, Smithsonian Institution, S/C Shell Gabon, BP 48, Gamba, Gabon. Emails: LeeMi@si.edu, rbuij@yahoo.com

[3] Mail address: Department of Recent Vertebrates, Institut Royal des Sciences Naturelles de Belgique, Rue Vautier 29, 1000 Brussels, Belgium. Email: osgpauwels@yahoo.fr

whale (*Megaptera novaeangliae*), and Atlantic humpback dolphins (*Sousa teuszii*).

In addition, some areas are key for species with restricted ranges – for example certain frogs and snakes that have low mobility. Protecting these small but key areas on the landscape helps ensure the continuation of a wide diversity of organisms. Other sites include areas exceptionally important for large-range species for at least part of the year. For example, areas with nutritious vegetation bordering large rivers or swamps provide critical feeding grounds for elephants, especially in the dry season when fruit resources are scarce. Protecting these key areas provides for their needs during bottleneck periods, increasing their chances of survival. Because such sites may also be of critical importance to other large herbivores (most notably buffalo, but locally also hippopotamus), a great effort should be made to protect them and assure their continued ecological functioning. These sites include: 1) the Rabi-Toucan area, including the Rabi River; 2) the Echira River basin, notably Lake Divangui to the Ngové River; 3) the Monts Doudou highlands and savannas; 4) the seasonally-inundated grasslands around Kivoro and adjacent lakes; 5) the Nyanga River; and 6) the entire coastal zone, with added emphasis on Loango National Park and lagoon/river mouths (see Fig. 1, page xxx).

It was also found that many migratory species depend on the Gamba Complex for their survival (see Fig. 2 page xxx). Examples of migratory species in the Gamba Complex of Protected Areas include migrants such as elephants moving around the forest consuming fruits or browse, or marine fishes moving by rivers deep into the forest, and global migrants such as sea turtles traveling thousands of kilometers to lay eggs on the beaches, humpback whales and fish traveling along the coast, Arctic terns flying between Antarctica and the Arctic, stopping to feed along Gabon's coast, and many forest birds traveling between Eurasia and Africa.

Elephant movements are an example of local migration, but migrations of other species may occur on a regional or even global scale, often on a predictable seasonal basis, and usually to exploit a particular resource with limited availability. Migratory birds include both seasonal long-distance migrants and intra-Africa migrants. Paleotropical migrants spend northern-hemisphere winter months (October - April) in tropical regions, and return to northern regions during summer months (May – September) to exploit seasonal resources such as arthropods in the temperate or Arctic zones. To survive, birds require that both their summer and winter habitats remain viable; alteration or elimination of either could lead to population declines.

Industrial development in the protected area, particularly for oil exploration, has resulted in major economic gains and stability for the country over the past 40 years, and resulted locally in significant immigration and development, with a suite of primary and secondary environmental impacts to the protected area (Lee *et al*. this volume). In order to track some of the most ecologically-important impacts to industrial areas, a suite of eight indicators is proposed in this paper for monitoring in the future. These indicators were selected as a result of four years of field observations by project scientists, as well as through an extensive consultation process of national and international stakeholders, to ensure collaboration and buy-in from many partners including the government. Indicators to be monitored respond to a range of primary and secondary impacts, include terrestrial and aquatic systems, and are both species-level (i.e. for legally-protected and endangered species) and landscape-scale (i.e. to ensure protection integrity for adjacent national parks).

Measuring these indicators will have a direct benefit in providing information for protected area management, oil impact management, the advancement of science and conservation models and training in Gabon. Establishing long-term monitoring and mitigation of known impacts on the environment is one way to leave a legacy favoring better management and protection of biodiversity.

2 Threats to the Important Biodiversity Sites in the Industrial Corridor

Human demands for natural resources threaten the biodiversity of the Gamba Complex. Major identified threats include oil exploration and development; logging and related hunting pressures; illegal hunting (commercial hunting of protected species or in restricted zones); non-native invasive species; low-standard oil operations; poor pollution response onshore and offshore; lack of sustainable land-use planning; lack of sustainable development strategies to provide economic alternatives to natural resource extraction; offshore trawler fishing within the illegal

limit of the coast; and onshore fishing using illegal techniques or exceeding quotas (WWF 2003). The government manages these threats assisted by non-governmental organizations and private companies through a variety of actions including the production of biological information, education, ecotourism, and law enforcement.

Impacts of different activities in the Industrial Corridor may represent a serious threat to species. Some of these impacts include forest fragmentation, threats to ecological connectivity, unchecked land-use change, poor waterflow management, illegal hunting, undefined decommissioning standards for the industry, introduction of alien invasive species, increased logging access, road effects on biodiversity, natural gas flaring, water and soil pollution, and low empowerment of land management authorities.

2.1 Primary and secondary oil impacts

Industrial impacts to biodiversity are both primary and secondary. The Energy and Biodiversity Initiative (EBI) defines primary impacts as those that 'result specifically from project activities, are normally limited to the project area and lifetime, and can often be alleviated with sound operational practices' (EBI 2003; 34). Secondary impacts are those that 'do not usually result directly from project activities, but are rather the result of other people's decisions and activities triggered by the project's presence' (EBI 2003; 34). The most common primary and secondary impacts that are detrimental to biodiversity can be "habitat conversion; degradation and fragmentation; wildlife disturbance and loss of species; air, water and soil pollution; deforestation; soil erosion and sedimentation of waterways; soil compaction; contamination from improper waste disposal or oil spills; and loss of productive capacity and degradation of ecosystem functions" (EBI 2003; 34).

The Energy and Biodiversity Initiative is a consortium of nine members – BP, ChevronTexaco, Conservation International, Fauna and Flora International, The World Conservation Union, The Nature Conservancy, Shell, Smithsonian Institution, and Statoil, which came together "to develop and promote practices for integrating biodiversity conservation into upstream oil and gas development" (EBI 2003;1). Shell Gabon is highlighted in its publication *Integrating Biodiversity Conservation into Oil and Gas Development*, under the chapter Mitigating Impacts (EBI 2003, 35-6):

> "For example, in Gabon, Shell's operations have been the catalyst for the establishment and development of Gamba, a town of currently about 6-7,000 people, many of whom work directly or indirectly for Shell. The presence of these workers, some of whom are second generation, has had an impact on the surrounding biodiversity through limited agricultural activities and hunting of bushmeat (recognizing that this is allowed within the local law as long as it is for local consumption and not trade). Shell has no direct control over Gamba, as it is a town with its own governance, but where Shell does have direct control, such as the Gamba terminal or the infield Rabi oilfield, it has put strict management controls in place, including controlling development, prohibiting hunting, limiting driving speeds and times, and managing emissions to minimize its impacts on biodiversity."

2.2 At-risk biodiversity sites in the Gamba Complex

Sites where the biodiversity of the Gamba Complex is threatened have been classified as severe (red), high (orange) and elevated (yellow) for the oil industry, and indicated for other sources (brown) as well (Fig. 3a, page xxx). Severe threats should be addressed immediately through management and mitigation plans, and monitoring. Severe threat zones include Toucan and Gamba, where threats include increased logging, hunting, habitat alteration for agriculture, oil exploration and human settlement. High threat zones include the northern edge of the Complex, Koumaga, Rabi, the Vera Plains, Nyanga River, Bongo River, major lagoon and river mouths, and the eastern side of Moukalaba-Doudou National Park. Threats in these areas include illegal hunting and fishing, unchecked slash and burn agriculture, road construction, non-native invasive species, breaks in connectivity, illegal trawler fishing and potentially-destructive tourism like big-game hunting. These threats are increasing and without appropriate mitigation measures will likely become severe. Much of the remainder of the Industrial Corridor is under an elevated threat because not all concessions are run with proper environmental management, and decommissioning plans for oil operators are not yet transparent or approved.

Decisions regarding further oil exploration, development, decommissioning, and access along the Rabi-Koumaga road will affect future threats to the Industrial Corridor. The road is currently managed by control points around the Rabi concession, restricting access along its entire length. Opening access will likely escalate the threat level for the entire Industrial Corridor to severe (Fig 3b, page xxx), and increase threats to the adjacent national parks, as the connectivity of natural habitats would be seriously compromised.

3 The Importance of Monitoring

How can oil operation impacts be reconciled with sensitive biodiversity-risk areas, species of conservation concern, and landscape connectivity? How can oil operations in a protected area maintain conservation standards? Energy and land management agencies need to understand trends in resources in their fields to help reduce risks related to uncertainty, and reduce costs of operations and restoration. These managers are increasingly asking for ecological monitoring to assess environmental condition, mark progress against management goals, reduce operational risk and exposure in biologically-rich areas, and provide early warning systems for adaptive management. Ecological monitoring standardizes the assessment of ecological health over time. Just as a doctor monitors a patient's heart rate and blood pressure as health indicators, natural vital signs can be used to evaluate the integrity of an ecosystem. Monitoring ecological vital signs provides early warnings of situations that require intervention, and helps frame research questions to determine chains of cause and consequence (see http://www.nature.nps.gov).

'Vital signs' are a suite of environmental measures that include biodiversity (e.g., species richness), ecological processes (e.g., seed dispersal), landscape changes (e.g., forest fragmentation), and physio-chemical changes (e.g., pollution of wetlands) measured over time to give a picture of ecosystem integrity. Ongoing monitoring of vital signs can indicate when management is on-track or not, and suggest how to meet management goals most efficiently.

4 Recommended Biodiversity Ecological Indicators

The scientific information generated by the Gabon Biodiversity Program in combination with an extensive stakeholder consultation process identified and recommended the following impact indicators to be addressed by Shell Gabon for biodiversity management, and to serve as a logical basis for the Biodiversity Action Plan framework that will be developed by Shell Gabon. Eight biodiversity impact indicators were selected on the basis of biological priority and operational impact, to assure maintenance of the ecological integrity and biodiversity of the Industrial Corridor. Complementary research should be conducted as necessary in the adjacent protected areas.

These are the eight biodiversity impact indicators to measure and monitor operational impact:

1. Habitat degradation affecting species of conservation concern.
2. Invasive species threatening habitats and native species in industrial areas.
3. Bushmeat hunting.
4. Ecological connectivity of protected areas.
5. Forest fragmentation due to industrial operations.
6. Coastal oil pollution.
7. Aquatic system changes due to industrial activity.
8. Impact of hydrocarbon pollution on wildlife.

Indicator selection was a product of years of field research and observations from the oil field and surrounding areas, and ecological theory, so that indicators would address priority issues in terms of impact, biodiversity and legality; be representative of a broad ecological array; have common, dominant structural elements; and/or affect species of conservation concern. The suite of indicators is meant to achieve broad ecological and thematic coverage – terrestrial, aquatic, legally-protected, impact-driven – which can support important management decisions at many levels. Peer consultation with science, industry, national, and international stakeholders was also important in the selection process, with input from the National Center for Scientific and Technological Research (CENAREST) of Gabon, the Wildlife and Hunting Department (DFC) of Gabon, the European Union, Wildlife Conservation Society (WCS), World Wide Fund for Nature (WWF), the World Conservation Union (IUCN), Gabon Vert, and others.

4.1 Habitat degradation affecting species of conservation concern

How can the primary impact of habitat degradation on threatened, endangered, rare and localized species of conservation concern be minimized? Habitat degradation is directly related to forest clearing (Dale *et al.* 1994). In 2002, total landtake in the Rabi field excluding roads was ~ 4.7 km^2, and landtake due to roads in the Gamba Complex ~ 260 km^2. Many species in Rabi were found only very locally, sometimes in the path of proposed land development. For example, Rabi is the second richest site for amphibians known in Gabon, with several species documented only there. Fish and tree species new to science were also found in precise localities in Rabi and Toucan, and are known nowhere else. However, although this information was communicated in advance, poor environmental management caused significant perturbation to these valuable zones. No follow-up measurement of biological response has been made. Species of conservation concern, which are often backed by legal mandate for their conservation, serve as a practical indicator for managing the effects of habitat degradation.

4.2 Alien invasive species threatening habitats and native species in industrial areas

Alien invasive species are considered one of the greatest threats facing biodiversity. The IUCN estimates the cost of the worldwide damage from invasive species at $400 billion a year, stating "the impacts of alien invasive species are immense, insidious, and usually irreversible. They may be as damaging to native species and ecosystems on a global scale as the loss and degradation of habitats." The United Nations Environmental Program (UNEP) considers invasive species to be one of the greatest threats to Africa's wildlife. The Energy and Biodiversity Initiative recognizes introduction of non-native species as a major threat posed by industry to the environment.

Intact, extensive ecosystems have a greater chance of resisting the incursion of alien invasive species. Since one of the characteristics of alien invasive species is their ability to adapt to disturbed environments, even minor disturbances can provide an opportunity for invading species. Once established, these species quickly spread along disturbed routes. Roads and rivers provide conduits that allow invasive species to penetrate deep into the forest, and zones of greater disturbance such as Koumaga and Rabi provide excellent colonization sites for invasive species, as well as sources for future invasions.

The little fire ant (*Wasmannia auropunctata*) is an aggressive, neotropical invasive insect that thrives in disturbed forests and is rapidly spreading around the world. This ant typically eliminates native ant species and other arthropods, affecting higher levels in the food chain, and is known to attack the eyes of large mammals and sea turtles, causing blindness and eventually death. Conservation scientists in Gabon consider it a high threat to the biodiversity in the country. The fire ant has invaded the Gamba Complex and is found in localized patches in Gamba town, Gamba terminal, Mayonami, Koumaga, southern Rabi, Lake Divangui and the Bongo River – several sites of biodiversity importance (see Fig. 4, page xxx). In Lopé National Park authorities are considering drastic measures like fumigating infested natural areas to attempt to manage the problem, but further investigation needs to be done on managing risk from this invader.

Savanna reptiles can be used to monitor impacts of the oil industry in forested areas. Certain reptiles are savanna specialists, and are not found in forested areas unless they are imported to sites where canopy cover is broken enough to allow their persistence. In 2003, Smithsonian scientists observed non-native savanna reptiles along the Rabi-Toucan roads, likely imported on equipment and able to survive in the relatively open microhabitats of roadways. Observations elsewhere have treated the agama lizard (*Agama agama*) as a bio-indicator of forest fragmentation, noting that where these invasive reptiles have colonized, native lizards might be out-competed (Pauwels and Vande weghe 2005). Monitoring savanna reptile invasions in Rabi-Toucan will help to understand distribution patterns and rates of spread due to industry, and serve as a measure of forest fragmentation, mitigating the local impact of biological invasions due to global industrial transport. Possible invasion by the Asian flowerpot snake (*Ramphotyphlops braminus*), an exotic species incidentally introduced through soil and plant transportation and already well established in Libreville (Pauwels *et al*. 2004), must also be investigated and controlled.

4.3 Bushmeat hunting

Bushmeat hunting is one critical secondary impact of Shell Gabon operations that stems from the increase in human population in the area. While bushmeat hunting is a local tradition, laws and company policies are meant to prevent it from depleting resources. One study on bushmeat pressure in the area in the late 1990s concluded that Gamba had the highest level of bushmeat consumption in Gabon (Thibault and Blaney 2003), and another study in Gabon found that bushmeat consumption increases with income (Wilkie *et al.* 2005), implying that Gamba's relatively high economic standard may result in higher bushmeat consumption than elsewhere in Gabon.

Hunting on Shell Gabon concessions is forbidden by policy, yet regularly practiced in the Gamba-Ivinga concessions. Smithsonian and Shell Gabon are currently working with Gabon's Wildlife and Hunting Department to remove traps and enforce Shell's no hunting policy. In May 2005, the first three days of surveys turned up 149 traps, 18 shotgun shells, two trapped animals, four camps, and three poachers. In Rabi, evidence of hunting is significantly lower than Gamba, partly because company policy is enforced. A recent Smithsonian study conducted inside and outside the Rabi concession noted a significant decrease in medium-sized game outside the regulated area versus inside of it – suggesting a negative effect of lack of enforcement (Laurance *et al.* in press a, b; Croes *et al*. submitted).

Direct patrols for hunting activity are a necessary measure to control the bushmeat trade, and should be complemented by faunal surveys to measure and track changes of animal populations in the field. Studies on the distribution and abundance of food resources for these animals will help describe how the spatial distribution of resources drives animal movements over time. Protecting key areas with important food trees in the Corridor will help ensure that populations of large vertebrates will have the resources they need to survive.

4.4 Ecological connectivity of protected areas

The Smithsonian Institution set out to determine the Industrial Corridor's value as a bridge for population movements using elephants as focal species. Elephants were selected because of their large-ranging movements and the fact that the Gamba Complex of Protected Areas is home to an estimated 15-20% of all African forest elephants.

Using a combination of methodologies in the Industrial Corridor in 2004, elephants were studied to identify patterns of connectivity across the landscape. Data, which are currently in analysis, suggest that elephants move throughout the landscape exploiting seasonally-localized resources and they seem to avoid centers of human activity, and infrastructure. In the early- and mid- dry season, elephants were observed in relatively large numbers in the papyrus swamps along the lower Echira and Ngové Rivers (on the border between Loango NP and the Industrial Corridor), the seasonally-inundated grasslands bordering Lake Kivoro (close to the border of the Industrial Corridor with the Moukalaba-Doudou NP), and the lower Nyanga River swamps (on the border of Moukalaba-Doudou NP; Fig. 5, page xxx) to exploit the low herbaceous vegetation and nutritious browse along the larger water courses. Near the end of the dry season, elephant density appeared especially high in patches of fruiting *Sacoglottis gabonensis* trees, one of only a few tree species bearing fruit preferred by elephants this time of the year (R. Buij, pers. obs.). An almost homogeneous clump of *Sacoglottis* trees to the southwest of the Atora oil field was particularly favored by elephants. When the wet season began, the elephants tended to disperse more widely in search of a variety of fruiting trees, primarily *Irvingia gabonensis* but also *Strychnos aculeata*, *Pentadesma butyracea*, *Panda oleosa*, *Poga oleosa*, *Diogoa zenkeri*, *Nauclea diderrichii*, *Tieghemella africana* and *Klainedoxa gabonensis*. Later in the wet season, they moved into places such as Rabi and the central part of the Industrial Corridor to exploit the fruiting *Pachypodanthium confine* and *Hexalobus crispiflorus* trees (see Fig. 5, page xxx). When the rains ended, the elephants again congregated along primary waterways, completing the cycle. During this annual cycle, elephants cover large distances, distributing seeds of important fruit trees in their dung. Interruption of this cycle would break the ecological connectivity of the landscape and its ecological processes, such as the regeneration of these key fruiting trees. This is especially obvious in the case of *Sacoglottis gabonensis*; in the 2004 dry season, almost every elephant dung pile examined in the Industrial Corridor held *Sacoglottis* seeds (from 1 to >100 per pile), and most piles containing seeds

were found in areas away from fruiting *Sacoglottis* trees (R. Buij, pers. obs.).

This initial baseline information provided a pattern of movement for these large mammals, and helped in identification of critical sensitive areas within the Industrial Corridor and adjacent national parks. We recommend using the same methodologies to monitor elephant patterns over time in order to understand connectivity patterns, seasonal movements, and trends due to human or natural causes. Monitoring elephants also will provide insight on bushmeat hunting and on the general state of the forest.

4.5 Forest fragmentation due to industrial operations

Forest fragmentation occurs when large, continuous forests are divided into smaller blocks by roads and other developments. Forest fragmentation correlates with loss of landscape and ecological connectivity, loss of habitat, loss of species, and structural and functional ecosystem changes that have implications even outside of the immediately disturbed areas. The degree of fragmentation influences landscape dynamics and biodiversity. Smithsonian's Biological Dynamics of Forest Fragments Project in the Amazon Basin is the world's largest and longest-running experimental research on forest fragmentation. Its research has shown that rainforest fragmentation leads to large structural changes and substantial forest dieback on the forest edge (Laurance 2000). Studies have also shown that breaks in the continuous canopy of a rainforest, from roads, pipelines, installations, have important impacts on populations of arboreal primates and understory birds that depend on cover.

Forest fragmentation is a primary impact of Shell Gabon operations on the landscape integrity of the Industrial Corridor (see Fig. 6a, page xxxi). In many cases Shell has assisted ground-level restoration of deforested sites with hydroseeding, yet canopy regeneration has not been investigated. The Rabi-Koumaga road and the road network throughout Rabi and Toucan have extensively fragmented the forest (see Fig. 6b, page xxxi). Technological advances in satellite imagery allow forest fragmentation to be monitored remotely and regularly over time at a coarse scale. Ground-truthing of patterns helps verify the remotely-collected data, and can be analyzed with software for assessment of fragmentation maps for future scenarios.

4.6 Coastal oil pollution

Periodically, crude oil washes up on the beaches of Gabon (see Fig. 7, page xxxi). These incidents are sporadically reported and seldom investigated, but there is a strong need for a plan to respond to a potential catastrophic event. The toxic properties of petrochemical pollution are well documented, including poisoning or killing of organisms directly through contact, ingestion or respiration, or indirectly through accumulation within the food chain. Hydrocarbon pollutants in the coastal environment threaten many forms of life, from microorganisms and invertebrates (plankton, mollusks, crustaceans, etc.) to fishes, marine turtles, and marine mammals at sea. On land, small terrestrial mammals (mongoose, genets, and beach scavengers) to larger animals of global conservation concern such as elephants, buffalos, crocodiles, game fish could be affected, as well as harming human populations congregating along the beach.

The Gulf of Guinea supports migration of whales that travel from the Antarctic to reproduce in tropical waters, as well as some of the most important populations of protected sea turtles and fish in the world. Additionally, four of Gabon's 13 national parks have marine coastlines. Oil deposition on the Gabonese coast is putting high-profile species and protected areas at risk. It should be addressed through an oil pollution monitoring program which could include field surveillance, sampling and laboratory testing of samples, followed by development of a reference collection from sample localities, information dissemination, coordination with government bodies for regulation, and an awareness program among operators to plan rapid and appropriate responses to spills. A coordinated approach can help minimize the risks to human and animal populations, reduce clean-up costs and minimize damage to reputation by having a response strategy in place, and encouraging greater preventative management.

4.7 Aquatic system changes due to industrial activity

Altered streamflow and wetland degradation are primary impacts of oil activity that affect water quality and aquatic system integrity. In Rabi and Toucan especially, poor waterflow engineering has blocked drainage and created artificial swamps in the forest. Some areas that have been re-contoured are now

prone to erosion and siltation, which can have enormous downstream consequences to entire freshwater systems. These forms of disturbance are exacerbated by chemical pollution from spills or careless placement and maintenance of machinery.

The biological response to these activities has not been measured in Gabon. Biological indices for measuring water quality require sampling of aquatic arthropods and analysis in a biodiversity laboratory to test for species composition as a measure of ecological integrity. Fortunately, advanced biotic indicator and sampling methods for water quality are available from other places, and offer a foundation for testing and development in Gabon.

4.8 Impacts of hydrocarbon pollution on wildlife

The presence of pollutants in the environment has been linked to a variety of chronic and acute toxicities in wildlife species. The classic work on the effects in DDT on raptors in the USA, for example, proved that environmental toxins can cause near-extinctions (Carson 1962). Wildlife and human exposure to crude oil and petroleum products garners some of the highest public concerns. Exposure to crude oils and fuel oils occurs through a number of avenues and affects many species worldwide. Annually, it is estimated that 3 – 10 million metric tons of crude oil and petroleum products are discharged into the environment. Although oil spills account for only 15% of wildlife exposure to petroleum, it is such spills that have allowed the study of toxic effects from exposure. More common sources of oil exposure for animals and humans are the production, refining and pipelines, transportation, and negligent disposal of waste oil and petroleum products.

The polycyclic aromatic hydrocarbons (PAH) and volatile components of oils (benzene, hexane, and toluene) account for much of the pathology resulting from exposure. Such pathologies include both acute health crises (e.g., oil spills), with associated high mortality and chronic insidious effects on health (e.g., decreased reproductive efficiency, behavioral modification) that place significant stress on wildlife, threatening survival. Eco-toxicology work could focus on species of conservation concern and those most likely to have exposure to and suffer effects from petroleum products, such as sea turtles, fishes, amphibians and marine mammals.

In Gabon, there has been little work to determine the exposure to petroleum products and residues in wildlife or humans. In particular, there has been no work determining the levels of PAHs in species commonly used as food by the local people (e.g., sea turtles, fish). Therefore, it is unknown what level of exposure from local food products is occurring in the human population. Food items sold in Gamba could be tested for PAHs as an indirect measure of the level of exposure of the local human population.

5 Conservation and development legacy

We have reached a critical time when we must act to guarantee the long-term sustainability of the Gamba Complex of Protected Areas. This legacy must be a true conservation and development model for the people and government of Gabon, the oil and gas industry, and the scientific community. Many of the critical elements are now in place: partnerships, solid biodiversity baseline data, indicators to monitor critical environmental vital signs, corporate commitment, and strong government interest and stakeholder engagement. The creation of the Loango and Moukalaba-Doudou national parks marked an important step in the overall protection of part of the Gamba Complex landscape. Similarly, all partners must look at the current and projected longer-term management of the Industrial Corridor, and the leadership that today's oil industry is providing – and tomorrow's could provide – to build the structure and resources for conservation and sustainable development of the Gamba Complex landscape.

Several potential scenarios have been suggested as conservation strategies that can accommodate industrial energy operations with conservation and protection of the Gamba Complex. These scenarios could include proposing the area as a future World Heritage Site, UNESCO Biosphere Reserve, or biodiversity sanctuaries and ecological connectors for the national parks (see Figs. 8, 9, and 10, page xxxi). Any of these scenarios or a combination of them, could certainly provide the legal, national and international recognition of the great value that this extremely diverse region of the world represents to society.

References

Angehr, G., B. Schmidt, F. Njie, P. Christy, C. Gebhard, L. Tchignoumba and M.A.E. Ombenotori. 2006. Bird surveys in the Gamba Complex of Protected Areas, Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Basset, Y., J. Mavoungou, J.B. Mikissa, O. Missa, S. Miller and A. Alonso. 2004. Discriminatory power of different arthropod data sets for the biological monitoring of anthropogenic disturbance in tropical forests. *Biodiversity and Conservation* 13: 709-732

Billes, A., B. Huijbregts, J. Marmet, A. Mounguengui, J.C. Mamfoumbi and C. Odzeano. 2006. Nesting of sea turtles in the Gamba Complex of Protected Areas: first monitoring of a nesting beach. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Boddicker, M.L. 2006. Large mammals encountered in the Gamba Complex of Protected Areas, Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Burger, M., O.S.G. Pauwels, W.R. Branch, E. Tobi, J.A. Yoga and E.N. Mikolo. 2006. An assessment of the amphibian fauna of the Gamba Complex of Protected Areas, Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Campbell, P., P. Rivera, D. Thomas, H.P. Bourobou-Bourobou, T. Nzabi, A. Alonso and F. Dallmeier. 2006. Floristic structure, composition and diversity of an equatorial forest in Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Carson, R. 1962. Silent Spring -- Houghton Mifflin, Boston.

Croes, B.M., W.F. Laurance, L. Tchignoumba, S.A. Lahm, A. Alonso, M. Lee, P. Campbell and C. Ondzeano. Submitted. Behavioral responses of African rainforest mammals to humans inside and outside a protected area. *Biotropica.*

Dale, V.H., S.M. Pearson, H.L. Offerman and R.V. O'Neill. 1994. Relating patterns of land-use change to faunal biodiversity in the Central Amazon. *Conservation Biology* 8 (4): 1027-1036.

EBI Energy and Biodiversity Initiative. 2003. Integrating Biodiversity Conservation into Oil and Gas Development. Conservation International, 58 p. www.TheEBI.org.

IUCN Commission on National Parks and Protected Areas. 1994. *Guidelines for protected area management categories*. IUCN Commission on National Parks and Protected Areas with the assistance of the World Conservation Monitoring Centre, Cambridge, UK.

Lahm, S.A. and J.P. Tezi. 2006. Assessment of the communities of medium-sized and large arboreal and terrestrial mammals in the Rabi/Toucan region of the Ngové-Ndogo hunting domain and southwestern Loango National Park. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Laurance, W.F. 2000. Do edge effects occur over large spatial scales? *Trends in Ecology and Evolution* 15(4): 134-135.

Laurance, A. Alonso, M. Lee, et P. Campbell. In press a. Challenges for forest conservation in Gabon, Central Africa. *Futures*.

Laurance, W.F., B.M. Croes, L. Tchignoumba, S.A. Lahm, A. Alonso, M. Lee, P. Campbell and C. Ondzeano. In press b. Impacts of roads and hunting on central-African rainforest mammals. *Conservation Biology*.

Lee, M.E., A. Alonso, F. Dallmeier, P. Campbell and O.S.G. Pauwels. 2006. The Gamba Complex of Protected Areas: An illustration of Gabon's biodiversity. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Mamonekene, V., S. Lavoué, O.S.G. Pauwels, J.H. Mve Beh, J.E. Mackayah and L. Tchignoumba. 2006. Fish diversity at Rabi and Gamba, Ogooué-Maritime, Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Mebiame, J.B. 2004. Second rapport national sur la diversité biologique. Observatoire national de la biodiversité, Republic of Gabon, 57 p. http://www.biodiv.org/doc/world/ga/ga-nr-02-p1-fr.pdf.

O'Brien, C., W. McShea, S. Guimondou, P. Barrière and M.D. Carleton. 2006. Terrestrial small mammals (Soricidae and Muridae) from the Gamba Complex of Protected Areas, Gabon: species composition and comparison of sampling techniques. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Pauwels, O.S.G., M. Burger, W.R. Branch, E. Tobi, J.A. Yoga and E.N. Mikolo. 2006. Reptiles of the Gamba Complex of Protected Areas, southwestern Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Pauwels, O.S.G. and J.P. Vande weghe. 2005. Les espèces exotiques invasives. Pp. 191-193 *in*: Vande weghe, J.P. *Akanda et Pongara. Plages et mangroves*. Les Parcs nationaux du Gabon. Wildlife Conservation Society, Libreville, Gabon, 208 p.

Pauwels, O.S.G., V. Wallach, J.P. Biteau, C. Chimsunchart, J.A. Yoga and B.C. O'Heix. 2004. First record of *Ramphotyphlops braminus* from Gabon, western-central Africa. *Hamadryad* 29(1): 138-139.

Primus, A., J. Harvey, S. Guimondou, S. Mboumba, R. Ngangui, F. Hoffman, R. Baker and C. Porter. 2006. Karyology and chromosomal evolution of some small mammals inhabiting the rainforest of the Rabi oilfield, Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Rodriguez, R.M., F.G. Hoffmann, C.A. Porter and R.J. Baker. 2006. The bat community of the Rabi Oilfield, in the Gamba Complex of Protected Areas, Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Rosenbaum, H. and T. Collins. 2006. The ecology, population characteristics and conservation efforts for Humpback Whales (*Megaptera novaeangliae*) on their wintering grounds in the coastal waters of Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Stevart, T. and V. Droissart. 2006. Diversity of orchids in the Gamba Complex of Protected Areas, Gabon. *In*: Alonso, A., M.E. Lee, P. Campbell, O.S.G. Pauwels and F. Dallmeier, eds., *Gamba, Gabon: Biodiversity of an Equatorial African Rainforest*. Bulletin of the Biological Society of Washington, No. 12.

Thibault, M. and S. Blaney. 2003. The oil industry as an underlying factor in the bushmeat crisis in central Africa. *Conservation Biology* 17(6): 1807-1813.

Trebaol, L. and C. Chaillol. 2002. Environmental and social impacts of oil industry activities in central Africa: a case study on the Gamba Protected Areas Complex (Gabon). World Wide Fund for Nature, Gamba, Gabon.

Wilkie, D.S., M. Starkey, K. Abernathy, E.N. Effa, P. Telfer and R. Godoy. 2005. Role of prices and wealth in consumer demand for bushmeat in Gabon, central Africa. *Conservation Biology* 19:268-274.

WWF. 2003. Strategy for the management of the Gamba Complex of Protected Areas, Gabon (2003-2008). Unpublished report.