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Best Environmental Practices for Seismic Exploration in Tropical Rainforest

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Abstract

Seismic exploration programs conducted in remote tropical regions typically emphasize operational efficiencies, security and safety, sometimes at the expense of mitigating environmental impacts in these highly sensitive environments.

Gran Tierra Energy Inc. and Walsh Environmental Scientists and Engineers have developed a set of benchmark environmental standards in Peru, based on 15 years of experience in the Amazon, that address significant impacts without putting onerous demands on the seismic contractor or inflating costs.

Significant direct impact mitigations include: minimizing clearing of rainforest vegetation for heliports, camps, drop zones and seismic lines; effective control of waste management practices in remote areas; journey management on roads; rivers and helicopter flights to reduce disturbance of sensitive wildlife areas. Significant indirect impact mitigations include: minimizing disturbance of normal community and economic activities in remote villages and small rivers; limiting access to remote areas by not opening trails or clearing rivers which facilitate pet collection, charcoal production, hunting and timber harvest.

The principal best practices include: no new road construction; limiting line widths and sizes of camps; restricting boat use; helicopter flight path restrictions, especially near sensitive areas; avoidance of Biologically Sensitive Areas (BSAs) in ground operations, restrictions on wood use, hunting, fishing and pet collection; removal of all non-biodegradable waste from project site; environmental education; transparent access negotiations, and community employment.

Investments in these benchmark environmental best practices for seismic exploration results in fewer impacts and good stakeholder relations for later phases of exploration

Introduction

Oil and gas exploration is increasingly becoming necessary in remote tropical areas with high environmental and cultural sensitivity. These tropical areas include countries in South America (Colombia, Ecuador, Peru, Bolivia, Venezuela, Brazil, Trinidad), Central America (Panama, Honduras, Nicaragua), Africa (Democratic Republic of the Congo, Uganda, Gabon Tanzania) and Southeast Asia (Malaysia, Indonesia, Papua New Guinea). Each of these countries has distinct regulatory frameworks, some with strict and specific environmental standards (Peru and Colombia), and others that are more permissive. Often oil and gas exploration companies, as well as seismic contractors, adopt policies of Best Practices irrespective of the regulatory environments where they are searching for hydrocarbon reserves in order to obtain sustainable social licenses to operate. A geophysical exploration program that includes seismic operations is the often the introduction of the company in a new area that may have had minimal economic and cultural contact with modern corporations. This trend is the product of good corporate governance which places a high priority of minimizing impacts, robust consultation with professional organizations and transparent involvement of local and international stakeholders in the design of exploration programs. There are several industry publications that present best practices.[1] This paper outlines some of the Best Practices that are being tested and employed in tropical environments throughout the world.

Definition of Best Practices

A definition of Best Practices is continual innovation and improvement, input and collaboration between oil and gas companies, contractors and external stakeholders. In the case of seismic exploration in tropical environments this innovation and improvement stems from the challenge of merging the engineering and logistical talents and experience of professionals in the industry with the requirements and ideas of environmental scientists and local populations. These Best Practices can be simple solutions largely copied from local inhabitants of tropical environments, such as the use of biodegradable vines to suspend cables and equipment along the lines, to the specialized use of high-resolution satellite imaging to identifying areas of secondary forest that can be re-used for fly camps and heliports. We have found that a multi-disciplinary approach to designing a seismic exploration program and associated Environmental Management Plan (EMP) yields cost-effective solutions to minimizing impacts.

Historical Trends in Seismic Exploration

Seismic exploration in tropical environments began in the 1960’s with the advent of multi-fold reflection seismology. The prevailing attitude was that the rainforest was so vast that it was believed to be virtually immune to human impact and exploitation.[2] Often little attention was given to environmental and social impacts. Seismic lines were commonly opened by bulldozers cutting long swaths through primary rainforest that fragmented habitat, opened remote areas to settlement and resulted in conflict with remote indigenous tribes. Camps were often sited purely for logistical convenience without considering sensitive biological areas, water bodies and communities. Waste management consisted of leaving waste on the forest floor and in unlined garbage pits as well as abandoning unwanted materials and equipment. These impacts have taken decades to heal and are often rightfully referenced as environmental abuse. The unfortunate result of this mismanagement of natural resources can be seen when a company revisits an area that had historical seismic operations.

These historic exploration programs were typically 2D seismic acquisition, consisting of long linear seismic lines tens to hundreds of kilometer in length spaced tens of kilometers apart. Even though the impacts were high where the program was conducted, the relative impact to the region was low since the density of lines was low. The use of 3D seismic acquisition since the mid 1980’s, which requires line spacing down to several hundred meters in some cases and a much more intense logistical intervention, is now regularly used in rainforest environments. Upon review of historical 2D data, some companies proceed directly to 3D seismic acquisition, since access, environmental and social sensitivity make two entries into an area less favorable. Therefore determining Best Practices in seismic is not just improvement on historical practices, but important for compensating the impacts of more intense 3D programs.

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[1] The Energy & Biodiversity Initiative Good Practice in the Prevention and Mitigation of Primary and Secondary Biodiversity Impacts
Oil Industry Operating Guideline for Tropical Rainforest; E & P Forum
Environmental Manual for Worldwide Geophysical Operators, International Association of Geophysical Contractors, 2001
Oil Exploration in the Tropics: Guidelines for Environmental Protection, IUCN- The World Conservation Union, 1991
The Oil Industry: Operating in Sensitive Environments, IPIECA-E&P Forum, 1997
Wetland and Waterbody Construction and Mitigation Procedures, Federal Energy Regulatory Commission Office of Energy Projects, 1994

[2] Oil Industry Operating Guideline for Tropical Rainforest; E & P Forum

Planning a Seismic Program

Typically a geophysicist will design a 2D or 3D seismic program to maximize information about the subsurface in order to minimize the uncertainty of drilling for hydrocarbons. Conversely he or she will want to minimize acquisition and logistical costs. Today's geophysicists now must take into account a variety of factors in seismic design, which have little to do with the subsurface geology. These include minimizing impacts in certain vegetation types, biologically sensitive areas, rivers, lakes and wetlands, communities and urban areas, protected areas, indigenous communities and specialized agricultural areas. The concept of acquiring data without regard to surface impacts has changed. A seismic program must demonstrate that impacts are minimized in order to get formal government approval and local stakeholder acceptance.

The planning process for a successful seismic program requires good biological, physical and community baseline information, which should be part of pre-feasibility studies and the Environmental Impact Study (EIS). The environmental baseline study should be designed to not only meet government regulatory requirements, but provide useful information to geophysicists. This is often an iterative process since the environmental study is often conducted at the same time as the design of seismic program. Typical biological information collected includes vegetation classification from satellite imagery and field observations, sampling of biologically sensitive areas (BSAs) to determine characteristics and density, identification of low sensitivity areas (agricultural areas, clearings, secondary forest), and animal migration routes. Typical physical information includes identification of geomorphically unstable areas (steep slopes, migrating or flooding rivers), unsuitable soils for camps (wetlands), navigitabilty of waterways, the presence of swamps and seasonal water bodies, clean sources for potable water and appropriate areas for discharge of treated wastewater, and climatic risks. Typical community information includes thorough mapping of communities; community restrictions on use (hunting and fishing areas, reserves, ecotourism); mapping roads, trails and waterways; hunting, fishing and native plant collection areas; sacred sites; and a detailed socio-economic baseline that feeds into a future community development program.

Public and stakeholder consultation during the EIS process is often perceived as cumbersome, expensive and time-consuming. It is useful, however, in delineating sensitivities that might be missed by environmental professionals, such as a river used for fishing, areas that have a sacred or traditional significance such as chonta palm groves or an area identified as important for future ecotourism. Incorporating these criteria is critical, since intervention could lead to deteriorated community relations escalating to work stoppages. The establishment of an outside oversight committee that consists of respected members of academia, non-governmental organizations, tribal leaders, local businesses (e.g. ecotourism operators) and government officials should be established to guide the EIS process and the implementation of the project, identifying key impacts and solutions.

Areas of high sensitivity are mapped in a GIS system, so that placement of lines, basecamps, fly camps and heliports and other areas of impact can be located in a manner that minimizes disturbances. Rules, such as offsets, are then developed for the field, which protect smaller sensitive areas that could not be reasonably mapped during an environmental impact assessment. The geophysicists, environmental and community relations team ultimately provide a design for government approval and a community license that demonstrates that the program is guided by sensitivity to the tropical environment as opposed to rigid requirements for optimal data collection.

Operational Best Practices

The seismic contractor should be involved in all aspects of the project design and the specific commitments to Best Practices. The contractor should have internal controls (Health, Safety and Environment; Community Relations Departments) that are well-versed in the Best Practices. Sufficient oversight of the contractor should be established to train and ensure compliance. Third party monitoring and supervision can be conducted by consultants, universities, communities, in addition to any government regulatory oversight. These management structures should be in place and tested prior to the execution of the program.

Line Cutting and Surveying

A 2D seismic operation in forested areas entails cutting a straight line through the forest to acquire seismic data. Line cutting practices has improved tremendously in the last two decades. The topical rainforest consists of a high canopy that prevents growth of under-story vegetation, making it relatively easy to manually cut a trail. These seismic lines are also access trails along which equipment is carried by hand with the aid of helicopters. For data collection purposes the lines are usually straight with any necessary bends around obstacles of less than 5°. Several countries have specific regulatory restrictions on line width which vary between 1.2 and 2 meters.[2] The lines must be of sufficient width to safely transport man-portable drills, cables and equipment along their length. For 2D seismic operations shotpoints or holes are drilled with man-portable drills of depths ranging from 3 meters to 20 meters. These shotpoints are drilled at precisely surveyed intervals usually between 20 and 200 meters apart. Specially trained laborers place and anchor an explosive charge at the bottom of the hole which serves as a source for propagating shock waves when detonated. These shock waves reflect off of underlying strata at depth and are received by sensitive geophones placed at specific intervals along the line. In 2D seismic operations, the lines that are cut contain both evenly spaced receivers and evenly spaced shotpoints. The resulting data collected allows for the geophysicist to image a 2D slice of the subsurface along the length of the line. For 3D operations, a grid of source lines are placed usually perpendicular to a series of receiver lines, the resulting data allows for a three dimensional image of the underlying strata.

Due to the effort of placing a shotpoint; the surveying of the exact point, transporting drilling equipment, the drilling and loading of the hole results in short term noise and disruptive activity around the location. The subsequent detonation of the charge can damage nearby buried structures, tunnels or burrows. Subsequently shotpoint locations are offset from areas such as lakes, residences, water wells and buried pipelines. Considerable effort is made to identify and avoid such sensitive areas usually through planning and scouting of the area before operations commence.

A recent development in Peru and Ecuador has been the establishment of offsets for biologically sensitive areas (BSAs)[3] **(Figs. 1 and 2)**. BSAs are small habitats of intensive animal resource-use, tending to attract large numbers and a diversity of species. These include clay licks **(Fig. 3)**, which are natural outcroppings that are consumed to neutralize seeds and unripened fruit and as a mineral supplement, additionally a variety of animals construct large nests in trees or animal dens on the ground. Watering holes are locations on water bodies that are preferred for bathing and drinking **(Fig. 4)**. Fruiting trees are highly dependent on fruit-eating birds and mammals that promote seed dispersal much greater distances than water and wind dispersal **(Fig. 5)**. Typically a large number of species of rainforest trees coexist in a small area due this effective method of seed dispersal. Leave-cutter ant farms were avoided to protect anteaters **(Fig. 6)**.

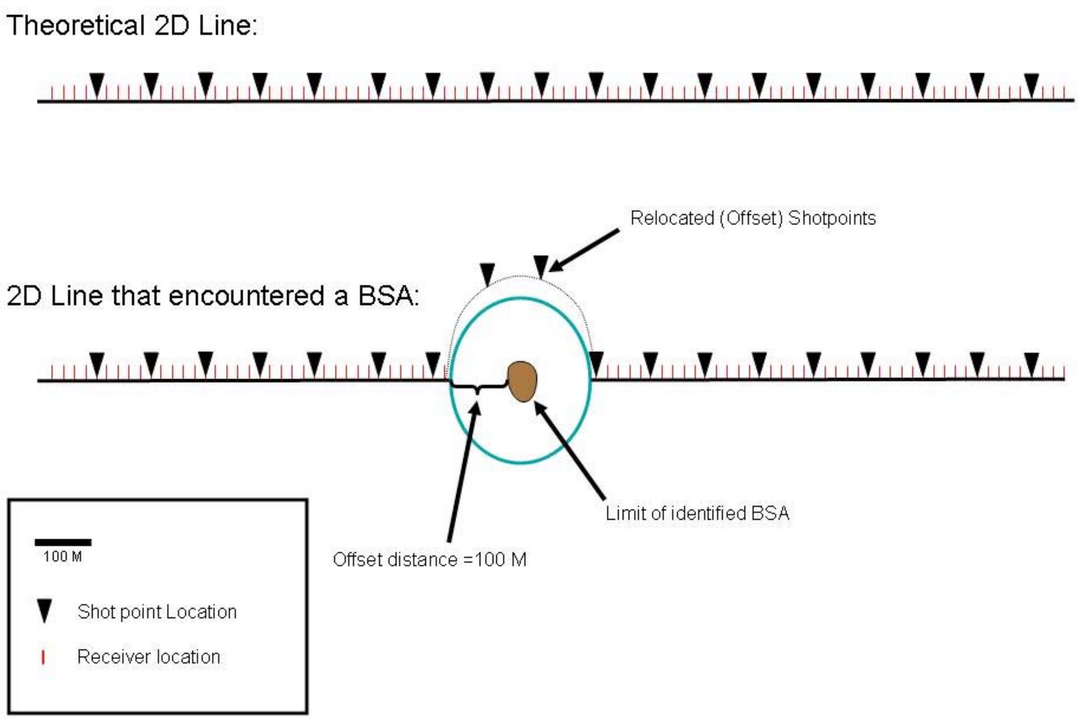

Fig.1 - Diagram for offsets of shotpoints around a BSA

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2 Reglamento Ambiental para Operaciones Hidrocarbiferos, 1215, Ecuador

3 SPE-111536-PP, "Microhabitat Protection during Geophysical Exploration in High Diversity Tropical Rainforest", Thurber, Valdivieso, Noboa and Silva, 2008 SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production held in Nice, France, 15–17 April 2008.

Fig. 2 - Notification of an offset due to an encountered mineral lick

Fig. 3 - Clay lick and bathing area in Yasuni National Park in Ecuador

Fig. 4 - Bathing areas used by Amazonian tapir (*Tapirus terrestris*)

Fig. 5 - Partially eaten fruit from an ungurahua palm fruit

Fig. 6 - Leave cutter ant farm important source of food for anteaters

Criteria are developed and tested by biologists in order to easily classify the BSAs in the field based on the size of BSAs, number and abundance of fauna species using the BSA, and functional importance to individual or groups of species. A basic training program is established for all seismic workers to explain BSAs and provisions for their conservation. Field biologists are deployed with the line cutting crews to identify, catalogue and avoid BSA's or other environmentally or culturally sensitive areas.

Post-execution audits have shown tha most of the BSAs, except those very near navigable rivers or roads, showed healthy use by fauna after all seismic activity was concluded. A few of these very accessible BSAs are being hunted post-project. Residual impacts to BSAs were determined to be less than in other seismic programs in similar environments during an independent audit.

Camps

The basecamp and flycamps can be located in previously deforested areas when possible. An innovative program to identify and reuse historic flycamps and heliports has been implemented in Ecuador. Multiple seismic exploration programs have been conducted in the Ecuadorian Amazon since the 1970s without reusing previously cleared areas for heliports and camps, resulting in unnecessary cumulative deforestation impacts. A remote sensing technique was developed to eliminate these redundant impacts by accurately identifying historic heliports and camps in mature tropical rainforest for reuse in a 3D seismic exploration program **(Fig. 7 and 8)**.

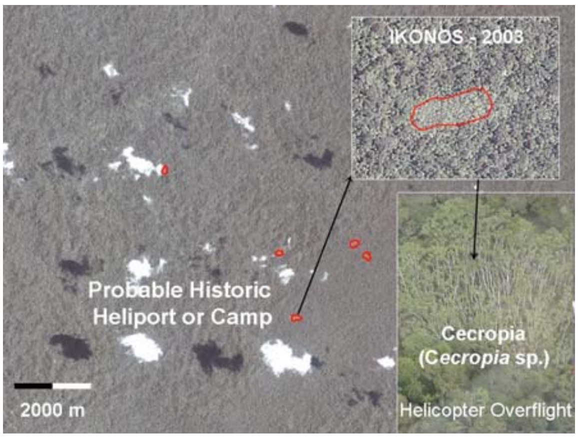

Fig. 7 - High resolution IKONOS imagery and helicopter photograph of a probable historic heliport or camp.

Fig. 8 - Seismic camp located at a historic heliport and camp, within a grove of secondary vegetation of cecropia.

A supervised digital classification technique was used to map vegetation in each of these images with the goal of identifying areas of low diversity vegetation for potential heliports and camps. Faint rectangular-shaped areas were manually identified on high resolution multiband satellite imagery. These features were enhanced using different band mixtures. They ranged in size from 0.1Ha to 1.8Ha and generally were aligned, indicating they may be associated with a historic seismic line. Prior to clearing a heliport and camp, a scouting team consisting of a surveyor, biologist, forestry technician and indigenous community member would fly over prioritized areas to aerially confirm. One program obtained permission to conduct seismic exploration in a national park only using these previously cleared areas. [4]

The harvest of firewood and charcoal is a significant impact in many rainforest areas. Restrictions should be placed on open fires, cooking should be done with gas stoves.

Light and noise impacts at camps can mitigated to prevent disturbance to surrounding communities and fauna in the forest. Typically, gas powered electric generators used for lighting, radios and battery recharging are buried below ground in specially designed pits to alleviate noise impacts.

Workers can be restricted to established work areas and restricted in their interactions with community members. Trail use near camps can be restricted to established transport corridors marked by flagging to prevent multiple routes resulting in soil compaction and erosion.

Waste Management

The principle source of wastes associated with seismic operations are the consumables of the labor force, and waste products from the camps and fly-camps. Best practices for waste management include reducing the source of wastes, proper treatment, classification of waste types, recycling and recovery and proper disposal[6]. The guiding principle in waste management should be reduction of wastes and the removal of wastes associated with the project. Recycling plastics and material at the basecamp are increasingly becoming standard practice. In previous years it was considered acceptable to bury wastes without regard to groundwater or the likelihood of biodegradation. Through stringent control only completely biodegradable solids may be buried in carefully constructed pits in designated areas. All waste products, with the exception of organic wastes are classified, packaged, weighed and returned to the base camp, the company and contractor are then responsible for removal from the operational area and proper disposal.

Heliports, Drop Zones and Fly Routes

Heliports are generally located near the basecamp or flycamps and used for the transport of equipment and personnel. It is our experience that heliports can be smaller than allowed by regulation, safety is not compromised for reducing environmental impact. The establishment of heliports is prioritized in areas of previous deforestation like fields, natural opening or areas of

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[4] SPE-95384-PP Reducing the Footprint of 3D Seismic in the Tropical Rainforest of Ecuador Thurber, Westlund, Benalcazar, SPE Asia Pacific Health, Safety and Environment Conference and Exhibition held in Kuala Lumpur, Malaysia, 19–20 September 2005.

[6] Waste Management Guidelines; E & P Forum Report No. 2.58/196

secondary forest. The noise and wind impacts require minimum distances from buildings and other areas of community use. Areas of less than 0.25 Ha with an approach cone of pruned vegetation are sufficiently large for smaller helicopters to operate. Trees are felled inward to prevent unintential impacts to surrounding vegetation and trees are cut above the soil so that sprouting is encouraged from the stumps after abandonment of the heliport.

Drop zones are established at more frequent spacing than heliports along the seismic line. Helicopters use a longline technique of transporting equipment in reinforced rope nets on 30m to 40m long cables allowing for dropping the equipment in natural or cleared openings in the forest without the necessity to land **(Fig. 9)**. This technique reduces noise and wind impacts, and reduces the need to open more heliports.

Flight path planning is very important to not only reduce fuel use, but noise and wind impacts to BSAs, communities and sensitive ecotourism or scientific research facilities. Exclusion zones, operating hours and heights can be monitored by onboard GPS units with alarms.

Fig. 9 – View from a helicopter long lining equipment into a Drop Zone

Waterway Use

Waterways are often the primary transportation corridors in remote areas. Community members may use small watercraft (dugout canoes, small speed boats, rafts) that are susceptible to swamping from wakes made by fast moving motor boats or barges or direct collision in the seismic program. Fishers, hunters, swimmers, cloth washing and residents along the banks of a waterway may be impacted by watercraft. Wildlife flee from high velocity and noisy watercraft. Provisions for speed and noise limits on watercraft are important to minimize impacts to the communities and wildlife.

In the past, headwater streams have been cleared of woody debris to extend the reach of fluvial logistics in remote areas **(Fig. 10)**. This practice reduces cost, but results in increased access that may induce hunting, fishing, logging and human settlement in otherwise pristine rainforest. A provision to prohibit cutting woody debris in these otherwise un-navigatable waterways eliminates this impact.

Fig. 10 – Opening a river for logistical access, this is difficult to restore and impacts areas upstream

Drilling

Man-portable drill rigs can be transported by vehicle where there are established roads. They can be disassembled and carried by hand by about three workers from a fly camp along the narrow trails on the seismic lines to shot points. These gasoline or diesel powered rigs only require an operating area of about 9 m^2 as and usually require 10 liters of water to facilitate penetration of the soil. In sandier soils addition of bentonite mud into the circulating water is necessary in order to seal the walls of the drilled hole and thereby reduce overall water consumption **(Fig. 11)**.

Fig. 11 – Drilling crew preparing to move portable drill

Layout

Cables and geophones are transported and stockpiled at heliports delivered to dropzones along the lines. This equipment is then hand carried and set out according to the program design. Biodegradable material can be used to secure the cables to trees and biodegradable flagging to mark the lines. Considerable effort is made for the logistics of ensuring that the layout is performed in an efficient manner minimizing foot traffic and the over use of trails.

Recording

The most common energy source for seismic exploration is an explosive charge buried at depth below the surface, however large machines that vibrate the surface can also be used. Vibroseis uses large, heavy wheel mounted vibrators that may cause significant damage to vegetation, surface hydrology and cause soil compaction. In rainforest areas, even with access vibroseis is usually not considered as an option due to its impact and unsuitableness for wet areas. Due to their high environmental impact and incompatibility with rainforest terrain, vibroseis is not considered to be a viable energy source for rainforest seismic operations.

An energy source using compressed air in an airgun submerged in water may be used to acquire seismic data in areas of standing water. Airguns are utilized when water depths exceed 2 meters as explosives can cause impacts to aquatic fauna (fish, amphibians, reptiles). When possible offsets are planned to avoid sensitive waterbodies, wetlands or seasonally flooded alluvial forest.

Pickup/Cleanup

Pickup/cleanup programs are planned and executed to ensure that all equipment, structures and trash are properly removed and disposed. Every shotpoint, heliport, camp, and drop zone should be re-visited and checked for abandoned equipment, trash or flagging. The restoration team's work should be audited.

Restoration

All access routes should be closed. Branches, brush, leaves can be spread on the surface of the cleared areas to impede use and promote re-vegetation. All temporary foot bridges over ravines and waterbodies can be dismantled and woody debris cut-up and spread on seismic lines.

Community Relations

In previous years consultation with the communities in the region was often initiated shortly before the contractor entered the area. We propose that a Best Practice is extensive community consultation at least 6 months before operations begin. The consultation process should include the contractor and clearly indicate the scope of the project, expected impacts, mitigating efforts for those impacts, and accurate timelines. Efforts should be made to carefully manage expectations including phased or staged compensation agreements and accurate explanation of the employment needs including the number of laborers needed, expected salary and length of time employed. Negotiations should be conducted in open community meetings, without personal gifts to leaders or other individuals. Where land title is held by communities, there should be no individual compensation, compensation must involve significant and obvious community benefits such as health and education initiatives. Community projects should avoid creating dependency and foster self-reliance and whenever possible, participation by community members should be encouraged. This participation will foster a sense of “ownership”. It is common practice to hire community “environmental guides” to be present with the line cutting and survey crews. These guides are versed in the local flora and fauna and also give a sense of transparency.

Efforts should be made to identify and support stakeholders such as local universities that may benefit from support for further biodiversity research in the region.

In seismic operations a significant number of laborers are required and are usually hired form the local communities, efforts should be made to educate and encourage these laborers in health, safety and environmental issues that can influence the communities. Recently a contractor started an evening class in the base camp teaching the laborers about basic rainforest ecology and the importance of conservation.

Specific Environments That Pose Difficulties

Cloud Forest

Seismic exploration in cloud forest environments is logistically challenging due to the steep slopes, high rainfall, dense vegetation and lack of existing road infrastructure. Helicopter use may be restricted by visibility and lack of flat terrain for heliports and drop zones. Some Best Practices employed in this environment are the use of utilizing high resolution digital elevation models (DEM) in pre-planning, the construction or stairways and aids for ascending steep slopes, and modified or dispersed fly-camps. Due to the straight and linear nature of the seismic lines it is important to minimize erosion by shoring or the use of staircases which are removed at the end of the operation. As a result of the limited flat areas suitable for fly camps, the camps my need to be distributed over a wider area, for example the kitchen and heliport in one area, the sleeping tents, latrines and water treatment in another depending on the availability of suitable terrain. In the absence of helicopter support pack mules are often used to minimize the number of repeat trips along the line to distribute equipment. Leafy material may be used to minimize erosion along the line.

Mangroves

Mangroves are highly productive and sensitive ecosystems located in tropical coastal areas. Significant potential impacts from seismic activity include: shock to aquatic fauna from detonations of airguns, removal of vegetation, small hydrocarbon spills, and acid drainage from disturbed sediments. Creation of new access roads and waterways should be avoided. If the mangrove area is restricted in size the seismic program can be designed to exclude shot points within the area and only allow receiving lines within the mangrove. Mangrove water depths may be too shallow for airguns, therefore drilling and detonations may be necessary. Deeper holes prevent cratering and need for backfill. As with terra firma forest, line widths can be limited to 1.5 to 2 meters. Doglegs in seismic line layout screen visual impacts. The orientation of seismic lines along the direction of a flood tide could cause erosion of sediments. Camps can be established on barges. In general the use of heavy machinery should be avoided.[5]

Large Lakes and Rivers

Large lakes and rivers are commonly encountered in seismic operations, careful pre-planning can often avoid these obstacles. In the event they cannot be avoided setback distances are required for sensitive riparian environments. Watercraft may be needed for deploying equipment, particular care must be exercised in fuel handling procedures and wake management. If an

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[5] Oil and Gas Exploration and Production in Mangrove Areas. Guidelines for Environmental Protection. IUCN, 1993

airgun is needed as a seismic source, the airgun should be the minimum size required for data collection, avoid oversized airguns, ‘pre-pops’ of half the normal energy should be used to frighten fish away from the area before operations begin.

As large rivers are very often used as main transportation routes for equipment, materials and supplies, including large quantities of gasoline, diesel fuel and helicopter fuel, the proper vessels must be used for transport. These vessels must be thoroughly audited prior to contracting and must include the proper certifications for the vessel and the crew. The vessel must include the appropriate kind and amount of spill containment equipment, including a chase boat to look for obstacles in front of the boat and to deploy the spill containment equipment should it become necessary. Frequent drills must be conducted to ensure that the deployment of this equipment can be done in a quick, safe and efficient manner.

Seasonally Flooded Areas

Seasonally flooded areas represent a challenge as during part of the operations the area may be dry and easily accessible along the seismic line. Generally careful pre-planning can determine which areas and when they are susceptible to inundation. Best practices in seismic operations in seasonally flooded areas include thorough planning and scouting for the choice of line orientation, priority of activities and determination of high ground for logistics. Generally areas with less than 3 meters of water may be surveyed and drilled while dry and data acquired when flooded. Small floats attached to a string and tied to the detonator leads on the other end should be used to avoid losing loaded shotpoint locations and thereby leaving un-detonated explosives in the ground. A subsurface detonation in a flooded area has a less impact than an airgun. Survey and drilling operations are completed in the dry periods with special attention given to flagging, often on tall poles firmly planted into the soil that will be evident in times of high water. Geophones may be located from boats using poles and cables suspended from retrievable floats.

Challenges in Implementing Best Practices

A common challenge to implementing Best Practices is the misconception that they are logistical hindrances and prohibitively costly. It is apparent that the introduction of biologists, ecologists and other professional into a seismic operation may raise costs slightly, but the long-term benefits of minimizing long and short term impacts are obvious. The costs associated with implementing Best Practices are usually a very low percentage of the total cost.

Additionally, involvement of regulatory authorities is critical for establishing a mutual understanding of the objectives and reasoning for such Best Practices. A tendency for some government bureaucracies is to look unfavorably on new processes and practices. A consistent effort is necessary to promote understanding and fulfillment of these Best Practices by the labor force.

Fig. 12 - Best Practices in Seismic Exploration in Tropical Environments and Benefits

Historic Practice	Impacts	Best Practice	Benefits
Seismic lines opened by bulldozer and heavy equipment	Deforestation, habitat fragmentation, induced hunting, settlement from improved access, erosion.	Hand cut lines, trails less than 2 meters wide. Restriction of cutting any tree greater than 20 cm in diameter (DAC). Avoid cutting of hardwoods.	Greater reduction of deforestation, quick recovery of vegetation, minimal improved access, more local employment
Large heliports and fly camps (up to several hectares)	Deforestation and loss of habitat, erosion, spontaneous colonization.	Minimize footprint. Restrictions on number, size and location of heliports and camps. Flexibility in location of helipads in order to take advantage of high ground. Leave in place shrubs, topsoil, root stock, endangered or protected species and plants used by communities for commercial use or subsistence. Stringent criteria in the selection of heliports and fly-camps to avoid BSA’s, inundation and areas of high water table.	Reduces area of impact to forest. Facilitates rapid recovery of ecosystem in areas of intervention.
Clearing debris from waterways.	Increased access for hunting, fishing, illegal logging and colonization	Prohibit clearing of waterways, use helicopters and trails to access remote areas.	Minimizes long term impacts of hunting, illegal logging and colonization
Use of charcoal and firewood for cooking.	Induces timber harvest.	Prohibit the use of charcoal and firewood, only gas and electric cookers.	Puts no pressure on communities to harvest wood for cooking.
Generators without noise mitigation.	Noise impacts to communities and fauna.	Located generators away from communities and with noise mitigation.	Reduces noise impacts.

Extensive lighting around camps.	Impacts fauna at night and attracts insects.	Directional and limited lighting.	Saves energy and reduces impacts to communities and fauna.
Mixed garbage disposal.	Non-biodegradable waste and hazardous waste uncontained in project area, impacts to soil, groundwater and surface water.	Separate biodegradable waste from non-biodegradable waste. Biodegradable waste is disposed in small composting landfills, other waste evacuated from project area and managed appropriated as a certified waste management facility.	Minimizes long term impact, prevent contamination of soil and surface waters
Direct discharge of wastewater to waterbodies.	Impacts to water quality of small waterbodies.	Use of latrines with infiltration fields a minimum distance from waterbodies. Use of black water treatment systems	Minimizes long term impact, prevent contamination of soil and surface waters
Informal storage and management of fuel and chemicals.	Uncontained spills that impact soil and surface ad groundwater.	Use of containment areas for fuel and chemicals.	Prevents contamination of soil, surface and groundwater.
Use of indigenous animals and plants as food supply for seismic program.	Depletion of fish, game and hardwoods.	Prohibit fishing and hunting. Prohibit purchase of indigenous fish and game from communities. Transport all wood form certified sources outside project area,.	Minimizes impacts, regional suppliers benefit from the supply chain
Project activities during high fauna activity.	Presence of workers, operation of watercraft and helicopters disturbs fauna.	Restrictions on dawn/dusk and nighttime operations.	Minimizes safety risks, minimizes impact on fauna
Earth movement with heavy machinery.	Exposes soil to erosion, compaction.	Minimize alteration of natural topography and drainages. Restrict use of heavy machinery.	Natural geomorphology and soil conditions are less impacted and require less effort for restoration.
No defined work areas, transport corridors, uncontrolled interaction with surrounding environment and communities.	Workers impact more extensive area and local communities. Numerous trails near fly camps.	Restriction of workers to defined areas.	Confines impacts to defined area that can be audited effectively and mitigated. Interactions with communities are control to ensure good relations.
Use of outside labor.	No employment benefits to communities.	Hiring policies that favor communities in direct area of influence of project.	Economic benefit to communities, technical and environmental training, and input from communities on project design and execution.
Untargeted compensation. No defined work areas, transport corridors, uncontrolled interaction with surrounding environment and communities.	Inappropriate assistance that can result in negative impacts.	A compensation plan that is based on assessing needs of community.	Provides basis for sustainable development assistance if exploration and development programs proceed.
No third party monitoring or audits	Lack of accountability to stakeholders	Oversight committees, monitoring and audits.	Allows for stakeholders to participate in project and provide constructive feedback.

Conclusions

A commitment to Best Practices in seismic exploration in tropical rainforests minimizes impacts to the environment, communities, logistics and long-term costs at every stage of seismic operations **(Fig. 12)**. Certain practices may be unique to particular challenging physiographic areas. Significant direct impact mitigations include: minimizing clearing of rainforest vegetation for heliports, camps, drop zones and seismic lines; effective control of waste management practices in remote areas; journey management on roads; rivers and helicopter flights to reduce disturbance of sensitive wildlife areas; transparent and inclusive community and stakeholder engagement are common strategies for all programs. Investments in these Best Practices for seismic exploration results in fewer impacts and good stakeholder relations for later phases of exploration.

References

Bodmer R E, Fang T Moya-I G L and Gill R,"Managing Wildlife to Conserve Amazonian Rainforests: Population Biology and Economic Considerations of Game Hunting." In Biological Conservation 67 (1993): 1–7.

Brightsmith D, Effects of Diet, Migration, and Breeding on Clay Lick Use by Parrots in Southeastern Peru. Ph.D. Disertation, Duke University, Department of Biology, Durham NC, USA, August 2004.

Emmons L H, Neotropical Rainforest Mammals: A Field Guide. University of Chicago Press: Chicago. 1997.

Fabara-Rojas J, “Saladeros: El Postre de la Selva”. Ecuador Terra Incognita, Ecuador Terra Incognita Cia. Ltda., November, 2007, No. 50.

Gilardi, J D, Duffey S S, Munn C A and Tell L A, “Biochemical functions of geophagy in parrots: detoxification of dietary toxins and cytoprotective effects”, Journal of Chemical Ecology, 1999, 25: 897-922.

Girton C, Chapman A, Hartog J, Stephenson M, Loppinet A, Harrison K, Read A, Oil Industry Operating Guideline For Tropical Rainforests E &P Forum Report No. 2.49/170 April 1991

Klaus G and Schmid B, “Geophagy at natural licks and mammal ecology”: a review, Mammalia, 1998, 62: 481-497.

Krishnamani R and Hahaney W C, “Geophagy among primates: adaptive significance and ecological consequences”. Animal Behaviour, 2000, 59: 899-915.

Montenegro O L, Natural Licks as Keystone Resources for Wildlife and People in Amazonia, Ph.D. Disertation, University of Florida, 2004.

Owens C, Rycroft D, Stephenson M, Norris G, Johnson J, Crame J, Inglesfield C, Greig A, Waste Management Guidelines E & P Forum Report No. 2.58/196 September 1993

Seidler T G and Plotkin J B, “Seed Dispersal and Spatial Pattern in Tropical Trees” in PLoS Biol (2006) 4(11): e344

Thurber M, Westlund D, Benalcazar F L, “Reducing the Footprint of 3D Seismic in the Tropical Rainforest of Ecuador” at the SPE Asia Pacific Health, Safety and Environment Conference and Exhibition held in Kuala Lumpur, Malaysia, 19–20 September 2005.