Inhibition halos in the remediation of Amazon soils contaminated with petroleum

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Abstract

We analyze the history of bioremediation of soils contaminated with petroleum in the Ecuadorian Amazon from 1994 to 2014. Although there were some technoscientific "successes," we argue that the opportunity to develop a process of scientific excellence was thwarted by lack of an institutional framework and the political will to oversee research and innovation. Dependence on foreign technology, insufficient internal coordination among research programs and institutions, corruption, lack of a national tradition of biotechnological innovation, the predominance of "biopeons," and a dichotomy between oil and the environment all influenced this process. We discuss these issues in relation to science and technology on the periphery and examine what is needed to consolidate technoscientific processes of excellence in those territories.

Keywords: bioremediation; biotechnology; contamination; petroleum/oil; Ecuador.

In the state of Ecuador, which in the past 200 years since the colonial era has not traditionally been a massive producer of "modern" style technoscience, there is renewed interest in encouraging research designed to solve local problems for the country's inhabitants and societies. This intent to reinforce the local is not new; for example, it can be seen from the 1940s on in various Latin American countries, some of which have been more successful than others, under the name of "substitution of imports," within the framework of dependency theory as proposed by authors like Prebisch (1949).

In Bolivia, a similar intent can be detected to generate science to serve the nation and not necessarily to contribute to "universal" knowledge (McGurn, 2010). This is a strategic attempt to avoid the formula of importing research interests, machinery and scientists. In other words, to move beyond a structure whose technological base is exogenous (Sagasti, 2011, p.23) and whose production responds to interests that are distanced from local needs (an internal brain drain, according to Polanco, 1986). Put another way, this is an attempt to avoid a sort of "mimicry by the periphery, which leads to copying even the worst products and processes from the center" (Arocena, 1995, p.45). These distorted structures exist, among other reasons, because of the widely-held idea that there are certain universal sciences, in which scientists around the world participate under equal conditions, even though what really exists is "an unmistakable correlation between the centers of political and economic power and the places where topics considered relevant from a scientific point of view are decided" (De Greiff, 2002).

Critiques of technoscientific dependency are not new (Polanco, 1986; Núñez, 1999; Sagasti, 2011). The fact that the local-global and South-North configurations of certain technoscientific structures lead to dependency and do not always represent solutions has been identified, for example, in technology transfer processes in the Green Revolution, which had negative socioeconomic and environmental consequences (Bajaj, 1988; McNeill, 2003, p.273-277).

But to what extent can the declarations and intentions of Bolivia, Ecuador and other countries lead to local processes of technoscientific excellence? To find out, we chose to investigate the development and application of a biotechnology aimed at solving a local environmental problem: the bioremediation of Amazon soils contaminated with oil. The case is interesting because it involves a biotechnology developed in a country that is highly dependent on petroleum – Ecuador – and that fits into a global sociotechnical system traditionally identified with negative environmental impacts, the movement of large sums of money, political and geopolitical negotiations, and technology etc.

We asked ourselves whether this biotechnology effectively contested technoscientific dependency and instruments of local governance in the twenty-first century, and whether it could become something more like a "social technology," as proposed by Thomas (2009). Reinterpreting Freire (1976), we wondered whether bioremediation was a "liberation technology," on the assumption that technology can be liberating provided it is localized, but it can also have the opposite effect: it can perpetuate systems that legitimize and foster inequalities at all levels. We analyzed whether or not bioremediation, in the form it took in Ecuador, perpetuated or reinvented traditional models of scientific dependency; whether it led to more problems than solutions or whether it was an act of scientific excellence on the periphery (Cueto 1989),[1] a transition towards a different model for understanding and benefiting from technoscience. Was this another typical case of exogenous technology or internal brain drain? Could this be merely one more way of creating “biopeons,” that is, technicians and scientists who do very little innovative research, and even less theory; people whose skills are devoted to applying and upholding paradigms constructed elsewhere, dependent on delocalized knowledge and technology (Cuvi, 2013)? Did bioremediation involve a scientific nucleus that was implanted, flourished and yielded results, giving rise to an “island of competence” (Oliveira, 1985)? Was it a sociotechnical system that applied human skills, economic resources and local biodiversity to solve an environmental problem? Initially, it looked as if bioremediation would be a case of development of a relevant or appropriate biotechnology (Sagasti, 2011, p.114).

We agree that the debate about scientific research must engage in constructive critique of development models to avoid wasting human and material resources so that science, in some regions, can stop being internally and internationally peripheral and “worse yet, satellital” (De Greiff, 2002). We believe that this article offers a micro-level analysis of how those resources are used and also – as we shall see – of how and why they get wasted. It helps explain what features of the institutionalization process encourage or prevent modern science from flourishing in peripheral contexts (Lafuente, Ortega, 1992, p.98).

Using local cases to debate technoscientific developments is also helpful if we consider that a given technoscience does not have the same effects in different contexts (Kranzberg, 1986; Núñez, 1999; Nieto-Galán, 2000). This [local case analysis] is based on the constructivist approach to studies of science, which argues that “some of the most important values governing scientific practice are fairly local” (Golinski, 2005, p.22), even though site-specific assessment and explanation does not mean we should avoid analyzing complex local-global and South-North connections.[2] This study sheds light on how technoscience is inserted, dovetails with, and relates locally and globally to other layers of culture like economics, politics, ideologies, power, academic and research institutions, education etc. Technoscience is not outside culture, but rather it is culture linked to local and geopolitical passions and interests, and to power, through which it develops emergent properties in each case.

Critiques of science and technology are part of an important tradition dating back to the 1970s, including more radical approaches as seen in Feyerabend (1982) and others associated with the strong program and constructivist sociology of scientific knowledge, which was focused on issues like the study of controversies, the naturalist focus of research and the examination of science as a culture (Golinski, 2005). We share the basic premises of this approach, although we do not deny the relevance of (and need for) technological knowledge and artefacts for humanity. From Kuhn (2001), we take the idea of considering moments of rupture and change, taken up by Latour (2008), among others; Latour furthermore suggests investigating associations between human and non-human actors at the same time. This examination of “non-human agency” also comes from environmental history (Worster, 1988).

In this article we allude to the (complex and maligned) idea of the peripheries of science, seen not from a deficit model but by examining cases of scientific excellence (Cueto, 1989) which appear to have been little studied (De Greiff, Nieto, 2005, p.63). We feel it is necessary to highlight excellence wherever it is found, among other reasons because the idea of a scientific periphery leads to deformed images of history and contemporary events (Restrepo, 2000), which do not seem good for the development of endogenous systems of thought. And while we employ a language that alludes to the "circulation" of ideas and technologies (instead of mere "diffusions" and "transfers"), that does not mean we intend to obscure a reality that still persists, namely the use of the terms "center" and "periphery" in the language and imaginary of different academic circles, at least since the appearance of Basalla's polemic article (1967),[3] or [to deny] that transfers of technology exist, as we shall see later on.

We follow the approach of viewing science as political, exploring scientific processes as part of power relationships. We agree that "scientific knowledge and technology are inseparable from the exercise of authority, control and domination" and that it is necessary to investigate "scientific practices in themselves in order to make their political consequences visible" (De Grieff, Nieto, 2005, p.61).

Lastly, this article belongs within the broader debate on biotechnologies at the present time. Despite their promises, some of these forms of technoscience have not come close to fulfilling what they set out to do; indeed, they have created certain threats (Bud, 1993, p.126). Partly because of this, we need to know more about them, in order to evaluate their governance mechanisms better (see Jasanoff, 2006 and Rifkin, 2009, among others).

The theoretical approaches listed earlier were reflected in our applied techniques: textual analysis, time-lines, observation, maps of actors and interviews. Our textual sources included bibliography on bioremediation (which is sparse, since there has been no research on this topic either from the history of science field or from STS studies); reports by an environmental consulting firm; notes in the press; academic theses; data about the state oil company (Petroecuador) and references to the oil industry in Ecuador. Interviewees included scientists and administrators at universities which carried out research on bioremediation, a civil servant at an agency handling remediation of petroleum contamination and another at the state oil company. The field work occurred at Estación Sacha Central, in the Amazon, where the Center for Research on Environmental Technologies (Centro de Investigación de Tecnologías Ambientales, Citvas) is located. Since both authors of this article were students at the School of Biology (Escuela de Biologia) at the Pontifical Catholic University of Ecuador (Pontificia Universidad Católica del Ecuador, Puce, referred to hereafter as the Catholic University) during the 1990s, we have first-hand knowledge of some of the details about this institution.

In analyzing the data we prioritized the identification of periods of crisis/change and tried to establish what led to them, regardless of their type (scientific, technological, institutional, legal, environmental, political etc.). The time-line and the map of actors allowed us to locate the protagonists over a period of two decades and trace their alliances, break-ups or important changes.

The article continues with a brief history of bioremediation around the world, of oil pollution in the Ecuadorian Amazon and the socio-environmental conflicts it has created. We then present the history of innovation, research and application of that particular biotechnology from 1994 to 2014. The "inhibition halo" was the metaphor that emerged from our work. It is inspired by the laboratory phenomenon that occurs when a bacterial stain spreads through petroleum from the center of a Petri dish out towards the edges; this indicates that the bacterium is useful for bioremediation processes (Figure 1). In this history, on occasion, inhibition hinders processes of innovation and investigation into science and

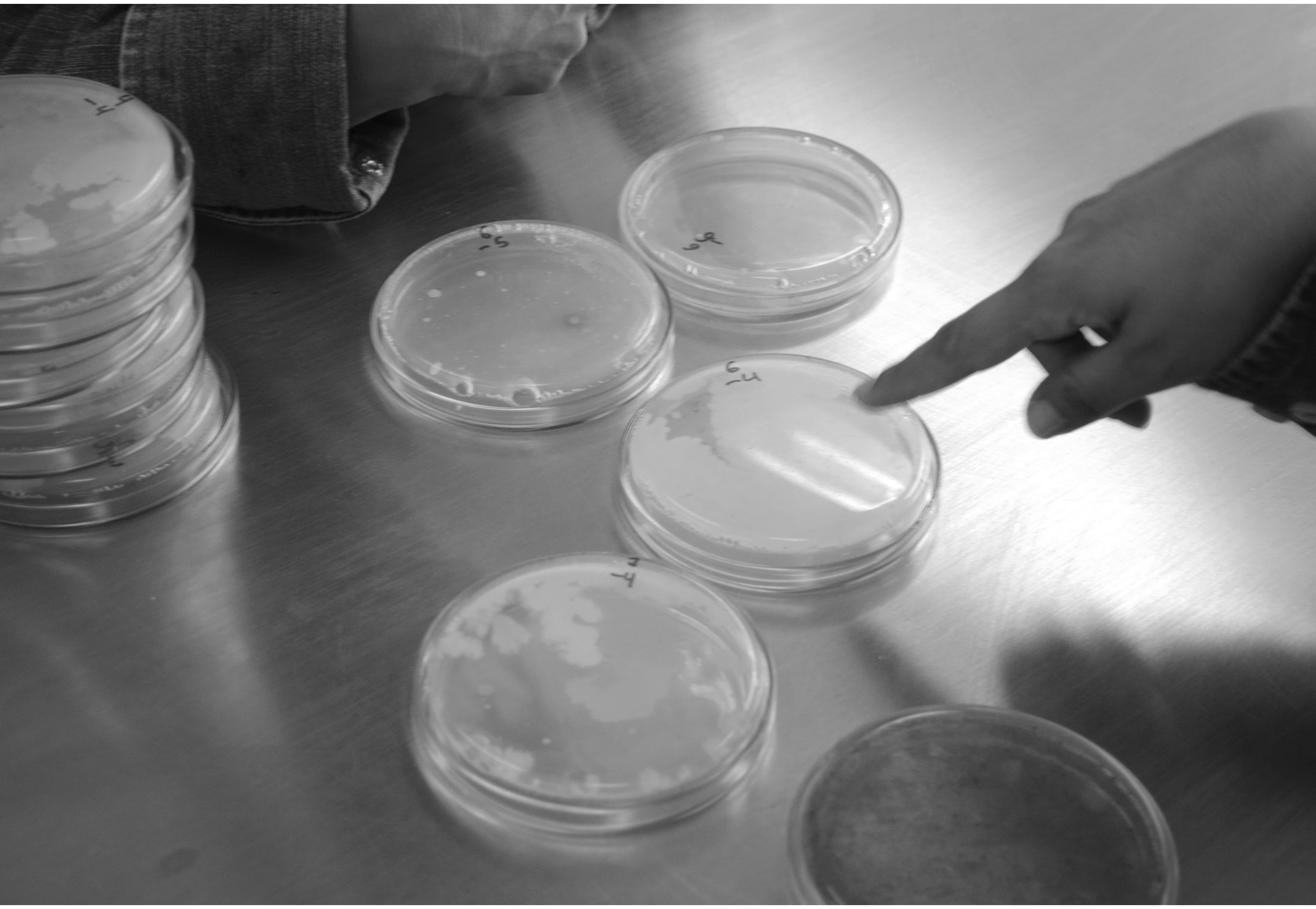

Figure 1: Inhibition halos in Petri dishes, Center for Research on Environmental Technologies (photo taken Dec. 2010)

technology. At the end of the article, we appropriate the metaphor and reverse it to refer to the potential role of institutions that manage science and technology to create an inhibition halo that would allow the pollution to be cleaned up.

Bioremediation of petroleum contamination

While bioremediation of hydrocarbons has been carried out for 70 years (Zobell, 1946),[4] the field took off after the oil spill from the Exxon Valdez tanker in Alaska in 1989; that was the point when bioremediation techniques were first applied on a large scale to marine ecosystems (Atlas, Hazen, 2011). In the seas, where hydrocarbons regularly leak from their underwater reserves into the environment, there are hundreds of species of bacteria, archaea and fungi that use them as a source of carbon and energy.

Most petroleum hydrocarbons are biodegradable under aerobic conditions, although some present imperceptible ranges of biodegradation. Light crude oils are the quickest to biodegrade. Polycyclic aromatic hydrocarbons, which are extremely toxic to plants and animals, are converted by bacteria into biomass, CO_2 and water, although to do this the bacteria may require an initial supply of oxygen and enzymes. Anaerobic breakdown can also take place, but much more slowly (Atlas, Hazen, 2011, p.6709).

Based on marine experience, Hoff (1993, p.477) proposed a three-stage model for bioremediation prior to 1993:

> I. pre-1989, primarily a research period, when bioremediation was little known outside the microbiology or hazardous waste community ...
>
> II. 1989-91, ... when bioremediation as a technology received wide attention and interest. At the end of [this] period, came a time of disillusionment as the promise of the technology was not always borne out by its use in real situations; and
>
> III. 1992 to the present. During this time, bioremediation has achieved a certain level of acceptance, with more realistic expectations than earlier, but the level of interest and attention has decreased considerably.

In the Ecuadorian Amazon, bioremediation was employed starting in the 1990s to treat soils contaminated by petroleum from c.1970 on, as well as current spills. Much of the crude oil that is mixed with the soil, cannot be retrieved for treatment at a station and reinjected into production, so it is collected by diggers and dump trucks and then transported to leveled beds for bioremediation. On these level beds, two main techniques are used to remediate the soil: composting and landfarming. The choice of technique depends especially on the amount of rain, soil and machinery available (Petroecuador, 2011, p.27; Entrevista 1, Entrevista 3, Entrevista 4). Composting is done in great piles that are stirred by machines so that oxygen can penetrate; in landfarming, the piles are not as high and aeration is static. In both cases, large quantities of microorganisms and molecules produced in laboratories are added to the soils (bacteria, yeasts, fungi, molds, enzymes, and cell components) in order to speed the breakdown of hydrocarbons. The bacteria are produced by an apparatus called a bioreactor. Sometimes nitrogen and phosphates are added to help the bacteria, which have a lot of carbon available in the substrate but no other elements (Atlas, Hazen, 2011, p.6709; Entrevista 1, Entrevista 3, Entrevista 4).

Bacteria are the group of microorganisms most used in bioremediation. They are collected in the field, especially in sites where there have been spills, taken to the laboratory, identified to the greatest possible taxon, and placed in Petri dishes along with hydrocarbons to determine their ability to break them down. If an inhibition halo appears in the Petri dish, it means the bacterium is able to "eat" hydrocarbons (Entrevista 3). Some bacteria can band together in consortia, which are groups that act together and speed up the process.

Oil contamination in the Ecuadorian Amazon

Until the early 1970s, Ecuador was overwhelmingly an agrarian country: it produced both monocultures, destined for foreign markets, and a range of diverse crops for local markets. The majority of the population lived in rural areas, there was little industrialization and the industrial fishing industry was only just beginning to emerge. But after the discovery of petroleum in the northern Amazon in 1967, Ecuador became an oil state. Since then it has encouraged the exploration, exploitation, transport and, to a lesser extent, refining of crude oil, sometimes through foreign companies, and sometimes with more participation from the state oil company.

The technology complex where crude oil is extracted has its epicenter between the towns of Lago Agrio, Coca and Shushufindi, which are on and surrounded by lands traditionally occupied by indigenous peoples. This complex has oil and multipurpose pipelines, pumping and treatment stations, housing, roads, helipads, airports, villages and towns etc. The oil for exportation is sent over the Andes and down to the port of Esmeraldas via the Trans-Ecuadorian Pipeline and the Heavy Crude Oil Pipeline.

Criticism of the oil industry in Ecuador over the last four decades has stressed its negative environmental, social, cultural and health consequences.[5] Many recent critiques have been linked to the lawsuit against the multinational Chevron (formerly Texaco) over damage to the soil, water, biodiversity and health of the inhabitants of the northern Amazon since operations began in 1967. For a little over two decades, Texaco caused major pollution via "pools" (*piscinas*, formed by the crude oil that escapes when a well is drilled), leaks from ruptures in the pipelines and the dumping of formation water containing heavy metals. When Texaco terminated its contract in 1990, it left close to half a million hectares of contaminated soil, as well as facilities that were still dumping formation water into the streams and rivers. In the face of this pollution and its serious health impact (some expert reports suggest the incidence of certain unusual types of cancer), a group of American attorneys, working with Ecuadorians, began organizing the indigenous peoples and peasant farmers who were affected, with the result that in 1993 they filed a class-action suit against Texaco in the New York district court, alleging that the decisions that had led to the contamination were made in the US, and violated US law. The suit called for remediation of the contamination and compensation payments for the damage to people's health and the environment. Since then, the trial has shown all the ingredients of a suspense novel, shifting between courts in the US, Ecuador and other countries as well as international tribunals. Among the more recent developments, in 2011, an Ecuadorian court sentenced Chevron to pay nine billion dollars to cover remediation for environmental damage, a figure that doubled when the company failed to issue a public apology to those affected. That ruling is difficult to enforce because Chevron has no assets in Ecuador, so an embargo has been requested in nations including Brazil, Argentina and Canada. In March, 2014, Chevron succeeded in getting the embargo of its assets banned in the US and it has appealed to courts like the International Tribunal in The Hague to transfer liability for the payment ordered by the Ecuadorian courts to the government of Ecuador itself. And in August, 2015, a US court ordered Ecuador to pay 96 million dollars compensation to Chevron, based on a bilateral investment treaty signed by both countries in 1993, a ruling that Ecuador has rejected.

This "trial of the century," along with the media attention given to the impact of certain oil spills in protected areas since the 1980s and to the frequent incidents of contamination that have occurred since then, were decisive in terms of calling the nation's attention to the negative impact of the oil industry. In more than one sense these events succeeded in getting most of the population in an oil-producing state to acknowledge that the country's economic wealth was associated with localized detriment to health and quality of life and damage to the Amazon. In part as a response to that sense and to social pressure, as well as international agreements on the issue, in 1999 Ecuador enacted legislative reform requiring companies to remedy the pollution they cause (Ecuador, 2001). And while this alone does not represent a guarantee that environmental remediation will be carried out, it has led to a rise in environmental remediation, which includes bioremediation processes.

Two decades of bioremediation in Ecuador

The circulation of bioremediation in Ecuador after 1994 can be seen as responding to two developments: when it was legitimized in the US and when contamination of the Amazon became subject to lawsuits and public outcry both on a national and international level. At that point nothing was known about bioremediation of Amazon soils (Entrevista 4), but the technology was seen as potentially useful for preventing and mitigating problems in areas that were under greater scrutiny, such as the Yasuní National Park, where the oil company Maxus began operating in 1992.

Ecuador's political and economic situation from the end of the 1990s up to 2005 could be described as unstable (with ousters of a series of presidents, a temporary closure of the banking system and dollarization) and neoliberal (with privatization policies and encouragement of investment by multinational corporations, weak government oversight of profits and operations, and faith in the market's ability to self-regulate). In this context, it appears that bioremediation presented not only a way to mitigate contamination, but also a new opportunity to intervene in the oil industry and obtain part of its profits, whilst simultaneously "greening" the industry's image. It appears to have been a development driven by a variety of political, economic and environmental interests, which technoscience could serve.

The idea of using microorganisms to bioremediate oil contamination was first introduced by foreign technicians brought in by the Maxus oil company in the 1990s: there was a desire to spread the word about a technology that had been gaining momentum thanks to its wide-scale use in marine contamination. Around 1994, Maxus organized a series of events including lectures by the expert Ronald Atlas, to which members of the Catholic University's School of Biology were invited (Entrevista 4).

We believe Maxus became interested in this issue when the company began extracting petroleum in the Yasuní National Park, under intense scrutiny from environmental groups. The Catholic University's School of Biology may have been influenced by the close relationship it had established with Maxus, providing consulting as the company began drilling in the protected area (observations in the 1990s), and then receiving facilities for a science station.

After the workshops held by Maxus, part of the 90m² Biochemistry Laboratory at the Catholic University's School of Biology began to be used for research on crude oil biodegradation using microorganisms. The laboratory director participated in this research, along with students and grant holders (observations in the 1990s). Initially, they were doing basic research: collecting microorganisms and testing their ability to digest crude oil. The shift to field-work happened in 1998, when the Project for Petroleum Exploitation and Sustainable Development in the Ecuadorian Amazon (Explotación Petrolífera y Desarrollo Sostenible en la Amazonía Ecuatoriana, Petramaz), financed by the European Community, hired the School of Biology to treat soils in the Cuyabeno protected area. The Project's staffers felt the Catholic University's group had some experience for attempting the first major bioremediation intervention in Ecuador. The results were positive and boosted the group's confidence and experience, under the leadership of a young researcher who took charge of this line of investigation (Entrevista 4). New contracts followed with private firms and with Petroecuador, in the wake of legislation that made remediation mandatory after 1999. A single contract could be worth over twenty million dollars (Petroproducción, 2006), funding which translated into a growth of infrastructure at the Biochemistry Laboratory, which moved into a 300m² space on the fifth floor of the north building of the Faculty of Exact and Natural Sciences (Facultad de Ciencias Exactas y Naturales), inaugurated in 2002. Both basic and experimental research was done there, such as isolating the dangerous and toxic *Enterobacter cloacae*, sampled at a location where waste and fecal matter from the Esmeraldas Refinery (on the coast) were mixed together. This bacteria was used to create a genetically modified organism, by transferring its genes to *E. coli*. The laboratory used imported technology (a sequencer, a gas chromatograph, flow chambers, refrigerators, reagents etc.). It ran various courses taught by specialists (Entrevista 4).

Everything was going smoothly until relations between the research group and the Cahtolic University deteriorated, when the university apparently raised its overhead costs. The group left the School of Biology and set up an environmental consulting firm offering remediation services including bioremediation, for which it was the only provider for a time. Research continued in the firm's laboratory, patents on processes and products were registered and expensive machinery was purchased and imported, including a windrowing system, which seemed more efficient than the traditional practices of composting and landfarming (Entrevista 4). The Catholic University, meanwhile, abandoned that line of research and the university was left out of the equation; in 2009, the Biochemistry Laboratory was turned into the Neotropical Center for Biomass Research (Centro Neotropical para la Investigación de la Biomasa, CNIB), which was not involved in bioremediation at all.

The environmental consulting firm's success led to the emergence of new remediation companies. In 2006 there were six companies authorized to contract with Petroecuador, although others wanted to be allowed to do so. Competition was intense: the new firms fought to be allowed in and be awarded contracts, while the established ones challenged the newcomers, claiming they lacked technical capacity and merely had connections among government employees in the state oil company. In our fourth interview, a civil servant on the environmental firm mentioned that

> remediation firms … started to proliferate, but they did not have the technology; the only requirement was to be able to pull strings over in Petroecuador … Behind the shareholders and members … there was always someone or other from Petroecuador who was pushing it, or the friend of a friend of someone at Petroecuador (Entrevista 4).

It was big business: according to a report in the Quito newspaper *El Comercio*, from 2004 to 2006, the Amazon District in the state oil company racked up over seventy million dollars in cleaning and remediation costs (Sallo, 28 sept. 2006). But this market began to collapse when questions emerged publicly about the growth of attacks on pipelines, linking them with the existence of remediation funds. The attacks had been occurring previously, but their number increased when remediation activities began. According to the organization Acción Ecológica (2006), in 2003 there were 34 attacks, a number which rose to seventy in 2005. One of the final detonators of this scandal was the oil spill of August 2006 in the Cuyabeno protected area, which was widely publicized by the media and drew attention to the alleged link between the attacks and the remediation firms. An ex-president of Petroecuador claimed that:

> It is a well-known secret that various employees of Petroproducción have links to or are proxy shareholders of the remediation companies, which is why the remediation companies have access to information about spills and bids by other firms … However, the peasant farmers are blamed for supposedly breaking the pipelines in order to get compensation payments (Acción…, 2006, p.8).

This is apparently how cronyism and client relationships began to wield more influence that the ethics of environmental restoration. This is where technoscience – the biotechnology to remediate contamination – revealed its intricate links to politics and power; it became both politics and power.

The alleged association between pipeline attacks and corruption in the awarding of contracts became the argument for preventing further external procurement, which gave rise to a move to centralize Petroecuador's remediation operations. Accredited firms continued to be contracted to handle exploration wastes, design treatment plans, draw up environmental impact and waste management reports etc., but they no longer performed remediation (Entrevista 4). We believe this disrupted the dynamics of a promising stimulus for environmental remediation, for science and technology, and for the economy etc. What had started out 10 years earlier as an alliance between a private oil company and a private university without funds or abilities (Maxus-Catholic University) evolved into a relationship between environmental consulting firms and the state oil company involving contracts worth millions of dollars. After that, the alliance was suspended thanks to dubious procurement practices.

Subsequently, the state oil company began its own process of innovation and application of biotechnology, at a time of growth in the power of the Ecuadorian State (from 2006 on). But this is just the first part of the story: the inhibitory effect of the state oil company's institutional structure can also be seen in other events that took place parallel to the relationship between the Catholic University, Maxus, Petroecuador and the environmental consulting firms.

Almost at the same time the School of Biology formed its alliance with Maxus and then with the Project for Petroleum Exploitation and Sustainable Development in the Ecuadorian Amazon (at the end of the 1990s), employees of Petroecuador had been supporting a bioremediation research program with the Central University of Ecuador (Universidad Central del Ecuador, UCE, referred to hereafter as the Central University), in Quito. In 1996, Petroecuador signed an agreement with the Faculty of Engineering in Geology, Mines, Petroleum and the Environment (Facultad de Ingeniería en Geología, Minas, Petróleos y Ambiental, Figempa), and a laboratory for bioremediation research was established there (Entrevista 1, Entrevista 2).

Chemists, biochemists, microbiologists, pharmacists and petroleum engineers from the Central University collaborated at this Faculty of Engineering laboratory. They had ambitious goals, especially as regards research into phyllosilicates and bacteria. They succeeded in isolating a bacterium christened "Rambo," which was capable of acting on the hydrocarbons most resistant to biodegradation. They came up with innovations, like a culture medium for producing biomass and a biotank for large-scale bacteria reproduction to substitute for the expensive bioreactor. However, these innovations gradually gave way to technology's traditional dependency, for example in the form of importing a bioreactor, or having laboratory analyses done in the US (Entrevista 1).

The agreement between Petroecuador and the Central University lasted 9 years and we have divided their activities into three phases: from 1996 to 1997, they collected and identified bacteria (the same thing the Catholic University had done), from 1998 to 1999, they researched the bacteria's specificity with regard to break down hydrocarbons, performing over nine thousand laboratory trials on contaminated soil brought from the Amazon; then, from 2000 to 2004, the research was transferred to the Biotechnological Sciences Laboratory (Laboratorio de Ciencias Biotécnológicas, Lacib), at the Sacha Central Station, in order to carry out experiments in the field in a space approximately 150m² next to the treatment plants for recovered crude oil. The technicians worked there until 2004, when the agreement ended (Entrevista 1, Entrevista 2).

It is not clear what Petroecuador's reasons were for terminating the agreement with the Central University; apparently it may be have been something as simple as a director (largely under the advice of technicians) stating in 2004 that research was not a priority and that the state oil company could handle remediation (Entrevista 1). Some time after that, questions began to arise about the contracts awarded to private companies for remediation work. With respective differences of scale and extent, this uncertainty about the reasons for terminating a scientific process of excellence has also arisen in institutions like the Agricultural Chemistry Institute (Instituto de Química Agrícola) in Rio de Janeiro (Faria, 1997). At a deeper level, we believe there may have been resistance on the part of the oil industry to anything labelled "bio," "eco" or "environmental," as well as to ceding control of a process that paid millions of dollars. Doubtless it was somewhat more complex than that (we were not able to interview the engineer most involved in the transition process), but it is clear that a promising program involving years of research and experience was ended virtually overnight.

Petroecuador terminated its relationship with the Central University and the remediation companies, but since state policy stipulated that contamination had to be remediated, in 2005 it launched the Project for the Elimination of Environmental Threats in the Amazon District (Proyecto de Eliminación de Pasivos Ambientales en el Distrito Amazónico, Pepda), under its subsidiary Petroproducción, to clean up oil pools and spills. For this project it hired recent young biotechnology graduates from the Army Polytechnic School (Escuela Politécnica del Ejército, Espe), a university located some 20km outside Quito. And at this point a crucial breakdown occurred. In the changeover process, the data, metadata, bacteria, methods, processes, etc. which Petroecuador had funded at the Central University were lost (Entrevista 3). The chance to move to a fourth stage, industrial production based on 9 years of research, was lost (Entrevista 1), because the scientists who were hired started from scratch (Entrevista 3). One proof of this repetition of the research is found in a presentation that technicians from the Project for the Elimination of Environmental Threats in the Amazon District gave at a biology conference (Jornadas de Biología) in 2008, in which they stated that:

> Over a period of twenty continuous months, we isolated, identified and characterized microorganisms in contaminated soils … that could potentially be used to degrade hydrocarbons … we also studied the relationship between strains [of bacteria] in order to form associations … As a product of this work, we now have a bank of 166 strains of bacteria of proven capacity (Hidalgo et al., 2008).

In other words, by 2008, the Project for the Elimination of Environmental Threats had spent almost 2 years replicating something that had already been done: prospecting, identifying and forming bacterial consortia. The new biotechnology engineering graduates hired for the Project were enthusiastic youngsters with no experience, who took on a major project amidst crude oil fumes, tubes of petroleum and gas burners that ran night and day. Petroecuador made no attempt whatsoever to take advantage of the [expertise of] Central University personnel (Entrevista 1) or of former Catholic University researchers to direct the laboratory, nor did it organize courses to transfer knowledge. They did not even save the bacteria and consortia; the young researchers started from scratch (again), prospecting, isolating, researching degradation capacity, and propagating (Entrevista 3). During this research we discovered that in 2005 everything started over from the beginning, as if the clock had been turned back to 1996.

This loss of expertise and material happened in part because Petroecuador's agreement with the Central University contained confidentiality clauses that prevented divulging any results or methodologies. The processes and products that came out of 9 years of research and innovation were not patented either (Entrevista 1). All of this created a halo that ended up inhibiting a technoscientific bioremediation process.

Figure 2: Abandoned bioreactor at the Laboratory for Biotechnological Sciences (photo taken Dec. 2012)

Figure 3: The old facility at the Laboratory for Biotechnological Sciences (photo taken Dec. 2012)

The Project for the Elimination of Environmental Threats in the Amazon District was faced with the challenge of remediating decades of contamination (left by Texaco from 1967 to 1990, and from incidents after that), but its progress was painfully slow, which is understandable given the lack of infrastructure. As a result, in 2007, it presented a project to expand the laboratory to 892m² (six times larger than the Biotechnological Sciences Laboratory), which required an investment of over three million dollars and took 2 years to build; the updated facility was named the Center for Research on Environmental Technologies – Centro de Investigación de Tecnologías Ambientales, Citvas – (Entrevista 3). After this center was ready, its inauguration was delayed a further year, but it eventually began functioning in 2010, with laboratories for bacteriology, phycology, molecular biology, environmental chemistry, microrrhizomes and phytology (Petroecuador, 2011). It was a better equipped facility than the Biotechnological Sciences Laboratory, but its main limitation was a lack of personnel to run it: at the end of 2012, while it had space for over twenty researchers, we confirmed during our visit that barely six were working there. And those few people were having problems carrying out their research, since much of their time was devoted to remediation work in the field (Entrevista 3). We observed some laboratories that were almost empty.

Another limitation of the Center for Research on Environmental Technologies was its technological dependency. It was equipped with imported machinery that in some cases, like the 100-liter capacity bioreactor, could have been manufactured locally (Entrevista 3). But the Petroecuador engineers placed orders whose specifications were geared towards acquiring European technology (Entrevista 3), thereby creating a sustainability problem, since no one knew how to repair those machines: we observed that the Biotechnological Sciences Laboratory's bioreactor, which had broken down years ago, was in a store room and had not been repaired. The machine, which had cost hundreds of thousands of dollars, lay abandoned in the old facility and a new one had been purchased for the Center for Research on Environmental Technologies (Figures 2, 3, 4 and 5).

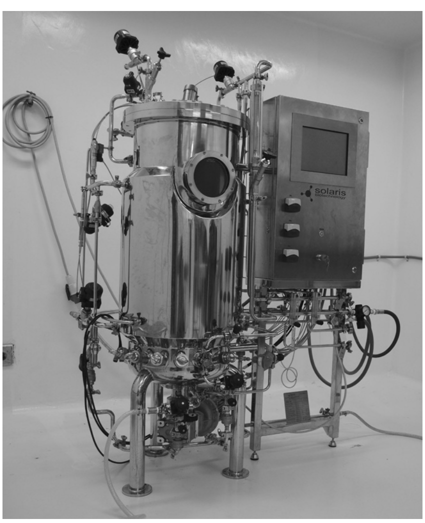

Figure 4: The new bioreactor at the Center for Research on Environmental Technologies (photo taken Dec. 2012)

Figure 5: The Center for Research on Environmental Technologies facility (photo taken Dec. 2012)

The Center for Research on Environmental Technologies' capability at the end of 2012 was greater, after 7 years of (re)acquiring expertise, as might be expected, since its staff were replicating a technological process that had already been developed by two independent research groups (at the Catholic University and the Central University). But we felt that problems persisted, such as the lack of a database (of organisms and documents) that would permit continuity in the case of personnel movement. And it was somewhat worrying, from our perspective, that the bacteria bank did not have a backup copy (Entrevista 3): a power outage, a human error, and even industrial espionage could overturn years of work (once more, although for different reasons). Petroecuador did not seem interested in observing the most basic protocols for innovation in biotechnology.

The Project for the Elimination of Environmental Threats in the Amazon District had a haphazard relationship with the universities. Dissertations on bioremediation were written in various universities, sometimes with funds from the Project, but with no visible direction or lines of research to connect them and no clarity in terms of mentorship. The work seems to have created individual rather than overall capacity, thanks to the dearth of systematization and an institutional framework for exchanging results. Some theses repeated results and reinvented experiments, with no cross-referencing, and the prevailing legitimization of scientific ability was based on foreign authors, texts and journals, thus rendering two decades of local research into bioremediation of Amazon soils completely invisible.

The Project for the Elimination of Environmental Threats in the Amazon District also failed to change Petroecuador's disinclination to pursue patents. One person we interviewed mentioned that "we don't want to patent anything" (Entrevista 3), which is difficult to understand in the world of twenty-first century biotechnology. The speaker justified that idea by saying that their goal was remediation, not patenting or publishing. Their scientific results were not published either (Entrevista 3), another way of establishing priority (although not ownership).

Eventually, the Project's technical activity was questioned by attorneys involved in the lawsuit against Chevron (Redacción..., 16 dic. 2006). The contaminated soil had not been remediated, and if it already seems lamentable that a technology should be needed to remediate something done by a third party in an inefficient and dangerous way, it is all the more so because to date, remediation has not been completely achieved. From 2005 to 2013, Petroecuador (via Petroproducción) had eliminated, sealed up and re-landscaped only 538 sources of contamination in the Amazon (spills, pools and pits), involving 260.549m^2. This was done through the Project for the Elimination of Environmental Threats in the Amazon District and the Plan for Complete Restoration of Environmental Threats in the Amazon District (Plan de Restauración Integral de Pasivos Ambientales en el Distrito Amazónico, Pripa), which started work in 2012 (Ecuador, 2014, p.6).[6] From 2013 on, these activities have continued under the Amazon Alive Project (Proyecto Amazonía Viva), run by Petroamazones (another Petroecuador subsidiary). Amazon Alive is proposing to clean up and rehabilitate 2,550 sources of contamination identified in the Amazon and to decontaminate over 5.300.000m^3 of soils (quoted in Ecuador, 2014, p.3).

Bioremediation is not becoming any less valid, interesting or relevant; on the contrary, it seems to be gaining political support for various reasons. One is that according to the 2008

Ecuadorian constitution, which recognizes the rights of nature, "nature has the right to restoration" (Art. 72), so that "integral reparation" of contamination is seen as state policy. Another is Ecuador's recent international campaign against Chevron, called "Chevron's Dirty Hand" ("La mano sucia de Chevron"), which has garnered support from politicians and artists, among others.

Bioremediation's inhibition halos

Petroleum has played a dual role in Ecuador: it has caused contamination and at the same time it has been a vital source of income for 40 years. In this scenario we feel that the technoscience of environmental remediation, which originated in North America, mostly with regard to marine ecosystems, circulated as an efficient intermediary, since it did not question the logic of oil industry, it minimized criticism by greening the industry, it was supported by a national and international framework of legislation and it fit into the capitalist system as one more business. But the microorganisms, bioreactors, biotechnology, diggers etc., promoted as potential mitigators were not sufficient to solve the contamination: institutional agency and political will played a more decisive role with regard to this technoscience. This sheds some light on the institutional structures within which biotechnologies circulate in the context we are studying.

The state oil company, which is responsible for the majority of spills currently occurring, and which inherited the areas that had been contaminated in the past, was the main protagonist of this story. Within the company, decisions were made, procurement models were designed, regulations were issued, agreements were signed, support or disincentives were provided etc. But it lacked the capacity to oversee a process of research, innovation and application of bioremediation technologies that had to be local because of the specific environmental impact involved. Links with the universities were severed for unknown reasons and then with the [remediation] companies because of accusations of corruption. It is hard to find a good reason to justify having begun the same research process twice over from scratch (three times, if you take into account the research done at Catholic University, even though it was not funded directly by Petroecuador); maybe part of the explanation lies in the idea that technicians are easy to replace, that they only have to follow a manual. Even so, that does not explain the failure to hire researchers at the Center for Research on Environmental Technologies, at least up until late 2012. One should not, in our opinion, rule out the influence of the resistance to environmental thought, given the confrontation between "environment" and "oil" that has played out in different ways in Ecuador, especially after Texaco pulled out in 1990, and that continues to be a source of conflict between the state, private companies and social movements of indigenous peoples, peasant farmers, and urban groups. How much did the dichotomy between oil and the environment influence things? Did Petroecuador officials deliberately disband and boycott an initiative that had a remediation component? Why was there support for discarding the Central University's results? Was it because [Petroecuador] wanted to be the central player and concentrate power at any cost?

Whatever the case, if there were indeed good intentions, there was certainly a lack on the part of the state oil company of any understanding of science and technology as complex cultural artefacts that require special management. The tradition among the government engineers at Petroecuador has been to keep the books, import technology and built infrastructures to extract crude oil, not to sustain a process of innovation. These civil servants have been peons of the global oil industry, not innovators, and perhaps they thought that biotechnologists could only be biopeons, people destined to apply technologies that come to the Amazon in packages, in black boxes (and other colors too), but not people who could come up with the ideas for those packages and build them. The scientists at Center for Research on Environmental Technologies became biopeons: technically capable, in the service of an unquestionable idea, they are workers at a research center where, for 6 years, there was little new research, less innovation, and where patents and disseminating knowledge were not part of the goals.

We believe the petroleum bureaucrats in the Ecuadorian Amazon, whether they are engineers or not, have not been in the habit of thinking about innovation, and even less of understanding the need for continuity in a technoscientific research process. Embedded in a matrix of technological dependency, they did not realize the importance of strengthening local scientific processes of excellence. The research studies carried out from 1996 to 2004 at the Central University, which were funded by the state oil company, were bound by strict confidentiality clauses that did not permit even a local transfer of knowledge. This confidentiality would be understandable if there had been a confidential use of the results or a process for patenting the methods, but it is incomprehensible that next to nothing was published or patented, at least up to 2013.

It cannot even be argued that, in monetary terms, bioremediation could be presented as a loss and not a gain, because even from an economics point of view, patenting new organisms, processes and machinery would have led to gains and savings. These and other questions point to the need to probe the imaginaries of the oil-company bureaucrats and notions such as the assumption that everything can be solved with infrastructure and imports. It is true that there were various "Petroecuadors," managers, engineers and administrators who came and went etc., but there were also people who were there throughout the whole process, whose imaginaries are of the greatest interest.

It was not for lack of scientists or financial resources that the project failed to take off. It was plagued by a naïve vision of technoscience, namely that it can be built on infrastructures and equipment, transfers and dependency, on replication, as has traditionally been the case in the oil industry's highly sophisticated, global, sociotechnical system. Perhaps the more well-intentioned believed that by bringing together specialists, texts and machinery, science and technology would happen by themselves, that they would flourish thanks to biodiversity (the bacteria).

It is somewhat paradoxical that the inhibition halo Petroecuador created around the existing capacities (by suspending top-level research and relations with other institutions) coincided with the one created by the state's political reforms designed to promote endogenous development and overcome cognitive dependency. But Petroecuador – a state company – was not the only actor involved in the process.

The public and private universities which had participated in bioremediation since the 1990s obtained some excellent results even though they were not able to capitalize on them over the long term through their own research programs. At the Catholic University, the motivation came first from the university's alliances with international oil companies, then from a project for international cooperation and finally from the government mandate for remediation. This led to a growth of human capacity, expertise and infrastructure, but as soon as the research group broke away, the university either could not or would not strengthen the field, even though it was of enormous environmental, scientific and economic interest. The line of research was removed from its academic setting and became a private company, which is not a questionable decision from a business point of view, but certainly is from the academic point of view, because it meant abandoning a promising line of research.

There was no ability to coordinate academic research on specific topics. Graduate theses were not cited, which cannot be attributed to the lack of access to them, since almost all dissertations are available on the Internet; a halo grew on local scientific culture thanks to failure to encourage circulation of each other's work. There was no local debate, and consequently, since those who were becoming experts were not talking to or debating with each other, it was hard for them to build a scientific community for bioremediation of Amazon soils. There was no systematization or broad diffusion of knowledge in the form of networks or continuing education and training, and no one published books or articles in specialized journals.

The scientists were dependent upon imported technologies. They were limited (or limited themselves?) to putting into practice an idea that technoscience takes place with imported technologies, using native resources in the form of biodiversity with the participation of biopeons. This happened regardless of positive experiences like the biotank and the development of culture media at the Central University. The idea of the biotank did not continue at the Central University because a bioreactor was imported. What was stressed was prospecting, isolating, identifying activity, reproduction and application, in a sort of natural history, without investing much effort in technology. It was not a complete internal brain drain, since the work involved a local problem, but emergent innovations were not sustained in this process.

One of the private firms that worked on remediation for some years carried out research, obtained patents and had some publications. Their experience was a positive transfer of knowledge from the university to the company about how to convert a product of academic research into a successful business. But this consulting firm also suffered marked technological dependency. Unfortunately, the remediation firms were related to an increase in attacks on oil pipelines and, while there were no trials, public outcry was used [as a reason] to stop hiring them, thereby losing their expertise.

We can see a profound interdependence between excellence and dependency in a complex sociotechnical system. All the institutions maintained dependency on technoscience, in the first instance by importing ideas to adapt and replicate them and then to sustain them with technology imported at great cost.

The track-record both of contamination and of bioremediation initiatives can be traced in the first instance to the oil companies Texaco and Maxus, respectively, and to the Project for Petroleum Exploitation and Sustainable Development in the Ecuadorian Amazon (which shows the impact of international cooperation in the second half of the twentieth century).

Petroleum seems to be capable of polluting everything, even science and technology. If the Maxus officials behind the first bioremediation workshops in the 1990s were thinking more about generating business than solving an environmental problem, they clearly succeeded.

Were the research into and use of bioremediation for petroleum contamination in the Ecuadorian Amazon an example of appropriate biotechnology? Yes and no. They were appropriate, because remediating contamination was (and still is) important and because a certain level of scientific excellence was reached. The mistake seems to have lain in the way the remediation was implemented. On the one hand, it required universities capable of maintaining research programs and scientists whose management skills went beyond limited programs and research interests. It required institutions with efficient technoscience managers, not just technocrats focused on building infrastructures out of blind faith that the technologies would transfer, as if technology were a neutral "medium." And all along what seems to have been necessary, at different levels, was political will. In our fourth interview we were told:

> I think it's clear that the country has the people and the ability to be able to generate this type of technology, which no one believed before. The failure or the disappointment so to speak [lies in] political influence over the research part. The scientific part and the political part don't get along, or they should be managed independently.

Along the same lines, Baiardi and Santos (2005, p.717) conclude their analysis of scientific development in Bahía (the periphery of the periphery) by noting that besides a series of institutional adjustments to relationships between the state, business and academia, change depends above all on social capital, the political will and commitment of the respective actors, and on institutional values like collaboration and trust.

Arocena (1995, p.45) has pointed out some factors that prevent the development of independent technological capacity on the peripheries. We have to agree with some of them in light of this case:

> Incompetence on the part of the state, which should be playing a leading role, and little ability to apply and enforce decisions of a technological nature.
>
> The existing reasoning modality which says that it is better for business to import technology than to produce it locally.
>
> Cultural dependency, according to which all foreign technology is better ... because it's foreign.
>
> Poor coordination between the leading actors in the process: state officials, business people, managers, scientists and technicians.

Sagasti (2011, p.144) also has some sound ideas; among the reasons for the lack of achievement in science, technology and innovation in the second half of the twentieth century, he includes "economic structures that lack internal coordination and have a pro-foreign bias, making it difficult to create their own capacity-building spaces for science, technology and innovation."

Clearly this debate is full of proposals, some of them more focused on national systems, like the actions proposed by Baiardi (2001) for Brazil to overcome its peripheral state, which include "proposing solutions for the tendency toward unfair international division of research labor which threatens to consolidate imbalances in the development of knowledge … [and] the consolidation of mechanisms of social control."

Final considerations

There was scientific and technological capacity that could have been oriented towards innovation. And there was economic investment. But doubts remained about how that capacity was managed and about the decisions that were made. It seems necessary to work on localized administration, whilst still taking advantage of the global game rules regarding technoscience, like patents and productive specializations. The idea that having biodiversity and funding means you can generate bioexpertise does not seem to work in and of itself. What is needed are more complex approaches in order to construct an inhibition halo around biotechnologies in Latin America, not to destroy them but to protect and empower them so that they will fulfill their promise to improve our lives. Otherwise, we are left with very emotive speeches that are devoid of content, and worse still, practical results.

In the context we have studied, and we would go so far as to say in many others related to petroleum scenarios, it does not seem to be a good idea for research and innovation processes involving environmental remediation of contamination to be handled directly by oil companies. Not just because their history is not one of environmentally-oriented research institutions, but because in a thorny issue like contamination, it does not seem appropriate for the same actor to be the banker, judge, accomplice, and entrepreneur, etc. It seems a mistake to give the job of clean-up and oversight to the polluter. Instead of a clean-up, what happened was replication of publicly-funded research studies, little or no transfer of information, and doubts about the lawfulness of certain activities, among other things. The state oil company at times constructed an inhibition halo that was destructive for scientific and technological remediation of contamination, without understanding, or remotely being able to manage, scientific and technological capabilities.

It seems that besides possessing good scientists, it is necessary to create, renew and strengthen policies based on expertise in endogenous processes, looking at particular cases rather than just dreaming about applying global theories of scientific development or replicating the (financial) successes of other regions and countries. We need to focus on what is really relevant and appropriate, not just what appears to be so. Maybe we need local ethics committees to supervise these decisions, along the lines Baiardi proposes (2001). Not international inspectors, but local committees to oversee whether science and technology programs are social, appropriate and locally appropriatable above all, so that programs with good results will be supported and inefficient ones will be penalized. Maybe we need major reforms in the science and technology systems for producing knowledge that are perpetuating the internal brain drain and dependency, training biopeons and managers who are comfortable in a place where innovation and the maintenance of independent, long-term scientific projects do not seem necessary. We need policies that encourage innovation instead of transfer, policies that abandon the assumption that with investment and infrastructure everything will solve itself, police that encourage patenting processes and products (although the idea of patenting life itself may be questionable, by not patenting we risk that expertise being illegally appropriated by biopiracy). Sagasti (2011, p.178-182) includes consideration of traditional knowledge and techniques and territorial specificity among his macro proposals. Analysis of local processes can lead to other series of ideas about more subtle factors that permit/prevent the consolidation of communities of scientific excellence on the periphery.

Beyond the questions which arise from this study, which, while they are to some extent ethical, are above all political and institutional in nature, we believe that bioremediation can support ecological restoration and protect the health of those who live in contaminated areas. This is mandated by the 2008 constitution of Ecuador, which recognizes both human rights and nature's rights. Bioremediation is a technoscience that can be social and liberating, but like any technology, how it acts will depend on who promotes it, and how and why they do so.

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NOTES

[1] The idea of scientific excellence (analyzed together with the scientific periphery) "is meant to emphasize that not all science in backward countries is marginal to the world's store of knowledge, and that scientific work in these countries has its own rules that must be understood not as symptoms of backwardness or modernity, but as part of their own culture and their interactions with international science" (Cueto, 1989, p.29).

[2] Our emphasis on the local does not mean we are unaware that the processes studied have repercussions in more distant areas (see De Greiff, Nieto, 2005, p.60, 62). Researching that aspect was beyond the scope of this article.

[3] Some even speak of "semiperipheries" (Ledesma, 2009) and "peripheries of the periphery" (Baiardi, Santos, 2005).

[4] A landmark case in this context was Diamond *vs*. Chakrabarty, in which a 1980 ruling by the US Supreme Court paved the way for patents on life itself, because it approved the patenting of a genetically modified bacterium for treating oil spills (Kevles, 1998).

[5] A pioneering study was done by Kimerling (1993). Regarding the impacts on biodiversity, see Bravo (2007).

[6] See also the website http://amazoniaviva.ambiente.gob.ec:8114/index.html.

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