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Scientists Raise Alarms about Fast Tracking of Transoceanic Canal through Nicaragua

Jorge A. Huete-Pérez,*[,†,♀] Pedro J. J. Alvarez,*[,‡,♀] Jerald L. Schnoor,[§] Bruce E. Rittmann,[∥] Anthony Clayton,[⊥] Maria L. Acosta,[#] Carlos E. M. Bicudo,[▽] Mary T. K. Arroyo,[○] Michael T. Brett,[◆] Victor M. Campos,[¶] Hernan Chaimovich,[∞] Blanca Jimenez-Cisneros,[⊗] Alan Covich,[⋈] Luiz D. Lacerda,[☼] Jean-Michel Maes,[⊞,♀] Julio C. Miranda,[★] Salvador Montenegro-Guillén,[△] Manuel Ortega-Hegg,[♀] Gerald R. Urquhart,[%] Katherine Vammen,[△] and Luis Zambrano[♁]

[†]Molecular Biology Center, University of Central America, Managua 14101, Nicaragua

[‡]Department of Civil and Environmental Engineering, Rice University, Houston, Texas 77005, United States

[§]Department of Civil and Environmental Engineering, University of Iowa, Iowa City, Iowa 52242, United States

[∥]School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, Arizona 85281, United States

[⊥]Institute For Sustainable Development, Mona Campus, Mona, Jamaica

[#]Center for Legal Assistance to Indigenous Peoples, CALPI, Bluefields, Nicaragua

[▽]Institute of Botany, São Paulo State Department of Environment, São Paulo, Brazil

[○]Instituto de Ecologia y Biodiversidad, Facultad de Ciencias, Universidad de Chile, Santiago, Chile

[◆]Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington 98195, United States

[¶]Centro Alexander von Humboldt, Managua, Nicaragua

[∞]Instituto de Química, Departamento de Bioquímica, Universidade de São Paulo, São Paulo, Brasil

[⊗]National Autonomous University of Mexico, Mexico City, Mexico

[⋈]Odum School of Ecology, University of Georgia, Athens, Georgia 30602-2202, United States

[☼]Institute of Marine Sciences, Universidade de Federal do Cearza, Fortaleza, Brazil

[⊞]Entomology Museum of León, León, Nicaragua

[★]CH2M HILL, San José, California 45242, United States

[△]Centro para la Investigación en Recursos Acuáticos, UNAN, Managua, Nicaragua

[♀]Academy of Sciences of Nicaragua, Managua, Nicaragua

[%]Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan 48824, United States

[♁]Instituto de Biología, National Autonomous University of Mexico, Mexico City, Mexico

Seeking economic growth and job creation to tackle the nation's extreme poverty, the Nicaraguan government awarded a concession to build an interoceanic canal and associated projects to a recently formed Hong Kong based company with no track record or related expertise. This concession was awarded without a bidding process and in advance of any feasibility, socio-economic or environmental impact assessments; construction has begun without this information. The 278 km long interoceanic canal project may result in significant environmental and social impairments. Of particular concern are damage to Lake Cocibolca, a unique freshwater tropical lake and Central America's main freshwater reservoir; damage to regional biodiversity and ecosystems; and socio-economic impacts. Concerned about the possibly irreparable damage to the environment and to native communities, conservationists and the scientific community at large are urging the Nicaraguan government to devise and reveal an action plan to address and mitigate the possible negative repercussions of this interoceanic canal and associated projects. Critical research needs for preparation of a comprehensive benefit-cost analysis for this megaproject are presented.

INTRODUCTION

In June 2013, the Nicaraguan government granted a concession to the Hong Kong Nicaragua Development Corporation (HKND) for the construction of an interoceanic canal across Nicaragua and various large subprojects (i.e., an oil pipeline, a railway and highway system, two deep-water ports, two

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Figure 1. Key features of the canal route across southern Nicaragua. Credit: S. Espinoza, A. Centeno, C. Solano.

international airports, a tourist complex, and a free-trade zone[1]). This concession was made without performing an independent environmental impact assessment in advance. The canal would connect the Pacific Ocean with the Caribbean Sea, traversing Lake Nicaragua, through the Caribbean lowlands, and ending at Punta Gorda in the Caribbean Sea shoreline. Lake Nicaragua, referred to locally as Lake Cocibolca, is an increasingly important regional source of water.[2] This is the largest lake in Central America (8200 km^2) and the largest freshwater tropical lake in the Americas. The canal will require excavation and dredging along a 278 km span, including 105 km through Lake Cocibolca, adjacent rivers, pristine rainforests and wetlands, and autonomous indigenous communities (Figure 1).

A preliminary description of the proposed Canal was distributed by HKND.[3] The depth of the Canal would vary between 27 and 29 m, with a maximum bottom width of 280 m. The sides of the Canal would be sloping, and it would incorporate two massive sets of locks: the Brito Lock—located in the west Canal segment near Rivas, and the Camilo Lock—located in the east Canal segment closer to the Caribbean Sea. These two locks would raise and lower ships between sea level at the Pacific Ocean/Caribbean Sea and the water level of Lake Cocibolca (30−33 m higher). For most of its length (except at two specific passing lanes), the Canal would be subject to one way traffic, and it would be able to accommodate ships up to 500 m long, 72 m wide, and drafting up to 23.5 m in seawater. This project would be one the largest civil earthmoving operations in history, requiring the excavation of approximately 5 billion cubic meters of material. This mega project, arguably the largest in the history of Latin America at an estimated cost of $50 billion, could have significant negative implications for this hotspot of global biodiversity and freshwater fish evolution.[4,5]

Although construction of a road to enable access by heavy machinery has recently begun (December 22, 2014), HKND's private environmental impact assessment is not scheduled to be concluded until five or six months later.

In an effort to provide an open scientific platform regarding the canal project, an international interdisciplinary expert panel met in Managua, Nicaragua, in November 2014. The aim was to identify technical and scientific questions associated with the Interoceanic Canal Project and contribute knowledge to environmentally sustainable human development. The panel's primary concerns fell into three broad categories: Water and Sediments, Biodiversity and Ecosystem Integrity, and Socio-economic Impact. Each category involves a number of complex considerations, rendering proper analysis a weighty challenge that is compounded by a lack of publicly available information from the Nicaraguan government, HKND Group, and contractors and consultants paid by the HKND Group.

The independent international expert panel emphasized that much is at stake from an environmental perspective: a unique tropical lake that serves as a supply of fish, drinking water, power generation, irrigation, and tourism; unique and abundant biodiversity and tropical rainforests in the east; and rich estuaries that would be transformed by some "sub-projects," recently expanded to include four tourist complexes. The Panel also considered social impacts of assigning autonomous indigenous community lands over to HKND Group ownership and the subsequent forced relocation of these populations.

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Figure 2. A view of Lake Nicaragua with the island of Ometepe in the distance. Photo credit: Thelma Salvatierra. (Permission granted).

CONCERNS ABOUT LAKE COCIBOLCA

Water and Sediments. Lake Cocibolca (Figure 2) has profound ecological, environmental, and economic value. Its biodiversity is unique including a once-large population of bull sharks (*Carcharhinus leucas*) and largetooth sawfish (*Pristis perotteti*) as well as several other endemic fish species.[6,7] The lake is a vital natural resource for Nicaragua, providing drinking water to several municipalities (e.g., Cardenas, Juigalpa and San Juan del Sur), as well as water for agricultural irrigation activities. Lake Cocibolca is also an important water reserve for the entire Central American region, which may increasingly experience fresh water scarcity as a result of climate change.[8] Lake Cocibolca's interconnected ecosystems are fragile and particularly susceptible to the effects of sediment resuspension due to its shallow depth (13 m average depth) and constantly mixing (polymictic) waters.

Lake Cocibolca also provides many ecosystem services essential to Nicaragua's economy, including ecotourism and fisheries. The building of a mega canal through Lake Cocibolca could alter the biological, chemical, and physical properties of the lake and of adjacent waterways to be used for the canal.[9] With the passage of hundreds of huge tankers weekly through the canal, it might also be difficult to prevent an increase in salinity in Lake Cocibolca. Subprojects and supporting infrastructure projects along the canal route could put enormous additional pressure on the lake as well through increased erosion, nonpoint source pollution and sewage discharges.

Water turbidity could substantially increase due to channel excavation, dredging, and future maintenance, as well as from ship traffic and other activities related to canal and subproject operations. Sediment resuspension can introduce large quantities of settled organic matter and nutrients into the water column, increasing the biochemical oxygen demand and eutrophication potential, eventually leading to hypoxia, a sharp decrease in biodiversity, and ultimately fish kills.[10] Furthermore, the high turbidity and reduced light penetration caused by excavation and maintenance dredging, along with regular shipping traffic, may harm the normal trophic dynamics[11] of the food web in the lake ecosystem. Dredged materials are also likely to contain heavy metals, pesticides, oil, and grease. Introducing these contaminants into the water column could deteriorate water quality, affecting locally irrigated agriculture, wildlife, and the livelihoods of communities that depend on the lake as their main drinking water supply. Even with the most advanced dredging methods (hydraulic or clamshell), plumes of turbidity would be created. Of potential concern is an increase in pesticide and mercury resuspension. Lake Xolotlán, to the north, is contaminated with mercury and intermittently discharges into Lake Cocibolca. Mercury released by resuspended sediments could introduce these contaminants into the food chain.[12] Chronic release of ship-hull chemicals and fuel leaks are also long-term concerns for water quality and food webs, while large spills from supertanker loads (Super Post Panamax up to 23 000 TEU) would be devastating.

The canal developer plans to deposit dredged material within the lake's borders to create new islands and along the length of the canal for agricultural purposes. As the sediment may contain toxic elements at levels above those established by international standards, an extensive plan for soil remediation may be necessary before its use in agriculture.

Migration of sediments into adjacent rivers may result in increased water levels that affect the riparian areas in several ways: operation of existing infrastructure (e.g., irrigation intakes) may be hampered; flood risk exacerbated by projected climate change may increase; local river navigation may become more difficult; and drainage of agricultural areas along the river,

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Figure 3. Forest area impacted by the canal in the Caribbean is home to at least 22 threatened or endangered species, some of which could be directly affected. Photo credits: Baird's tapir by Benjamin Urquhart; Eyelash Viper by Gerald Urquhart; White-lipped peccaries group by Michigan State University. (Permission granted).

as well as drainage to the Indio Maíz Nature Reserve, may be impeded.

Will There Be Enough Water? A fundamental concern is whether the watersheds will provide enough water in the future for all required uses after the canal and subprojects are operating. Even when using water-recovery basins for lock operations, large locks require large volumes of water. Water for lock operations will be supplied by Lake Cocibolca and damming of rivers to create the artificial lake, Atlanta (395 km^2), a lake similar to Panama's Gatun Lake. All of these actions may reduce discharge into the San Juan and Punta Gorda rivers on the Caribbean side, reducing their flow rate by millions of cubic meters per day once the canal is in operation. With reduced flow, the morphology (e.g., the width, depth, slope, and sinuosity) of these rivers would change, and the effect could include deposition of sediments, encroachment of vegetation, and a narrowing of river widths.

Nicaragua is among those countries considered most vulnerable to climate change,[8] with drier, warmer conditions leading to increased severity of droughts and catastrophic weather events. Those impacts would be aggravated by environmental degradation, such as deforestation, which already occurs at 1−5% annually,[13] or approximately 70 000 ha per year.[14] Thus, the need for water availability would become more pressing over time.

BIODIVERSITY AND ECOSYSTEM HEALTH CONCERNS

Protecting Nicaragua's Natural Resources. Nicaragua is within the Transition Zone between Neotropical and Nearctic flora and fauna. The different forest types found across the west-east precipitation gradient contain a high level of biodiversity. The country's Caribbean forests are within the Mesoamerican Biological Corridor, and the Pacific coast, including Lake Cocibolca, is an important migratory bird corridor.[15]

The proportion of aquatic habitat in relation to terrestrial ecosystems in Nicaragua is high due to Lake Cocibolca's vastness (7% of Nicaragua's territory is aquatic).[16] The lake offers much in the way of artisanal fisheries and ecotourism, which depend heavily on several native fish species,[17−19] and has been an important habitat for freshwater fish evolution (e.g., cichlids). Ecotourism has been considered as the country's second highest generator of foreign exchange.[20] Conserving natural resources, ecosystems, and biodiversity is important to achieving Nicaragua's equitable and sustainable long-term development.

The Canal May Severely Affect Nicaragua's Biodiversity. A project on the scale of the proposed interoceanic canal has the potential to cause direct and indirect impacts on Nicaragua's extremely rich biodiversity, the loss of which would be irreversible. These impacts must be anticipated, monitored,

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and mitigated before, during, and following the construction of the canal.

During the construction and operation of the canal, the quantity of nutrients in the lake's water column is likely to increase due to sediment resuspension, augmenting the possibility of algae blooms, including toxic microalgae. Sediment suspension may affect aquatic biodiversity, changing the composition of organisms living in the sediments and the water-sediment interface. These changes could affect top predators (e.g., visually foraging fish) and the availability of insects for migratory birds, such as the immense flocks of swallows (*Hirundinidae*) that migrate to Lake Nicaragua's western shore to feed on clouds of *Diptera* that blow off the lake.[21] They could also promote the invasion of foreign aquatic plant and fish species (Tilapia for example), affecting the viability of native biota. The arrival of some invasive invertebrate species in bilge water can exacerbate the loss of native species.[22]

Dredged sediments deposited along sea coasts and estuaries during canal construction and maintenance could damage coral reefs, sea grass beds, mangrove forests, and Bluefield's *Raphia* swamps. All of these habitats are critical refuges for biodiversity,[23−25] the importance of which is well documented.[26,27] Mangroves can enhance the biomass of coral reef fishes.[23] They and coral reefs prevent the erosion of coastal shorelines during storms by absorbing wave energy and reducing the velocity of water passing through the root barrier.[28] Coral reefs support more biodiversity per unit area than tropical rainforests[29] and components of their biodiversity have been found to produce promising compounds of pharmaceutical value.[30] Sediments deposited along the canal route could affect the biodiversity and health of the San Juan and Punta Gorda rivers in the east and of the Brito River in the west.

The creation of Lake Atlanta (395 km^2) could become a focal point for the introduction of invasive aquatic plant species. If not designed properly, it could also create a concentration of pollutants, causing serious eutrophication in the new lake basin similar to the experience of Three Gorges Dam in China.[31] Because water quality within Lake Atlanta's basin will directly affect all species that come to rely upon it, this artificial lake's water quality will depend on treatment plans and biodiversity conservation strategies that are yet to be revealed. Lake Atlanta is to be created within the Punta Gorda Nature Reserve and immediately next to Cerro Silva Reserve; it could alter forest ecosystems, coastal mangroves, brackish lagoons, wetlands, and rainforests. The area is home to at least 22 threatened or endangered species (tapir, sloth, seraphim, opossum, and jaguar, among others,[32] (Figure 3), some of which could be affected.

The physical barrier presented by the canal would drastically inhibit animal movement and gene flow along the Mesoamerican Corridor and numerous conservation reserves.[33] The Jaguar Corridor, the initiative to which Nicaragua is a signatory, will be interrupted by the up to 520 m wide water channel, as well as highways and other infrastructure. Aimed at connecting jaguar populations and facilitating genetic exchange, the initiative is a critical element of a long-term survival plan for the Mesoamerica jaguar and its broader ecosystem.

Given the large number of unknowns, the unique characteristics of each ecosystem, and possible devastating impacts, a long-term plan to monitor and mitigate loss of biodiversity is of utmost importance.

SOCIO-ECONOMIC RISKS

The proposed canal and subprojects are being promoted as the largest engineering project in the world, one that will help create jobs and lift Nicaragua out of extreme poverty. Will this be true? Nicaragua should prepare and publicly vet a detailed economic assessment that includes not only a cost-benefit analysis but also considers externalities associated with national economic development, environmental impacts, social equity, human rights, and legal and national security issues.

Is the Proposal Economically Viable? The Nicaraguan Government has not published a detailed business plan for the canal. A thorough economic study for the most important engineering project currently in progress should include an analysis of the competitive environment, the possible impacts of technological change, and future changes in the cost of oil and shipping. Projections need to factor in the growth rates of the major world economies, future shipping volumes, the cost of capital, and the sensitivity of profitability to variability in these factors. Planned expansions of the Suez Canal, the Panama Canal, and the potential for Arctic ship traffic through the Northwest Passage,[34] where ice is melting due to climate change, should be assessed in any business plan for the Nicaraguan canal.

An appropriate methodology would factor in the value of environmental assets that may be lost as a result of the development: for example, ecosystem services, biodiversity, ecotourism, and food and water security. The social and environmental impacts from unintended migration of displaced indigenous and *mestizo* populations to nearby nature reserves, and subsequent deforestation, should be carefully considered.

Human Rights Issues. Besides imposing considerable environmental risk to the country's ecosystems, one obvious consequence of the canal and subprojects is the expropriation of a vast amount of land. A likely outcome is forcing indigenous people off their land and the displacement of at least 277 communities and more than a hundred thousand people,[35] including settlements from protected indigenous territories such as the Rama and Creole. Provisions must be made for multiple, large-scale, human population migrations. A host of support services will need to be provided to people displaced by the canal and subprojects, including those displaced and host populations forced to receive displaced persons. A well-developed, internationally sanctioned, humanitarian strategy will be needed to respond to people displaced by canal development.

Of special concern is the state's legal obligation to consult the numerous indigenous and Afro-descendant communities located along the planned canal route. More than 50% of the canal will cut through communal indigenous and Afro-descendant territories. Nicaraguan law prohibits the sale, lease, or seizure of communal indigenous lands. A comprehensive socio-economic impact assessment and full consent of these communities should be obtained in advance of any actions that affect these communities. Indigenous peoples have filed a petition to the Inter-American Commission on Human Rights (Washington, D.C) requesting international measures to halt the canal's construction, along with independent, comprehensive, impact assessments.[36,37]

Potential Risks to National Security. At least two factors pose security threats that have not been publically addressed by the government. The first is that a large shipping center can become a foothold for organized crime. The preferred route for

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arms, narcotics, and precursor chemicals for narcotic production is via container ships. Second, terrorists direct their attacks not only at their enemies, but also at the economic interests of those providing services to their enemies, placing the canal and Nicaragua at risk for terrorist activity. Careful local planning and cooperation with international law-enforcement agencies are needed to establish security systems and equipment to preserve national security. The Nicaraguan government should ensure that HKND Group designs all facilities to minimize these security risks. Either the HKND Group or the Nicaraguan government should invest in state of the art screening and scanner technology. Protocols for intelligence-sharing with key partners will need to be established and maintained, readying the country to deal with international organized crime and terrorism.

CONSIDERATION OF INTERNATIONAL BEST PRACTICES

International best practices are well established for evaluating environmental, technical, financial, economic, and social impacts. HKND and the Nicaraguan government should adhere to those best practices, which include independent feasibility and environmental studies, public consultation and debate, use of scientific input, and transparent communication with multiple stakeholders in advance of the project. For example, the publication of all reports generated to date would contribute greatly to determining which additional studies are needed and would also invite a much needed exchange of opinions among local and international scientists. Some additional research needs and questions that should be addressed to inform a comprehensive benefit-cost analysis are suggested in Box 1 and Box 2. Box 3 provides a factual statement about alternative canal routes as suggested in the corresponding reference.

Three strategic considerations emerge as preeminently important, requiring immediate action:

- *Determine the financial viability of the Project and its impact on national development.* The Nicaraguan government and people will benefit greatly from fully disclosing business and economic projections to the public. This will facilitate evaluation by independent experts, allow for the expression of various points of view on project feasibility, mitigate growing social unrest, and minimize irreversible loss of economic, environmental, and social assets.
- *Perform an independent scientific evaluation of the potential impact to water quality, ecosystem health, and biodiversity.* The Nicaraguan government and people will gain immensely from an independent and comprehensive review of the environmental impacts of the proposed canal.[33] Receiving expert input from national and international experts, with no personal stake in the canal or its subprojects, will serve the interests of all Nicaraguans, who rely on the nation's forests, fresh water resources, and unique biodiversity. Preserving biodiversity is also of global interest.
- *Comply with relevant laws and meeting social needs.* The Nicaraguan government has the obligation and authority to protect the interests of all its citizens. The canal route will cut a swath across a vast area of indigenous territory, leading to the forced displacement of indigenous peoples and impacting their culture, language, and livelihood. For this canal project to proceed, international and Nicaraguan laws require that these communities first provide their "free, prior, and informed consent".

Box 1. RESEARCH NEEDS

Water and Sediments

- Ecological conditions within Lake Cocibolca, including all important ecosystem components: water quality, benthic flora and fauna, fish, mammals, and seabirds should be assessed and baselines established.
- Initial data collection should include core samples, bathymetric, water currents and circulation studies of the lake, and characterize variability in water quality. Geologic stratigraphy of the lake bed should be carried out as the proposed channel is much deeper than the lake bed. Lake bed sediment should be analyzed for biological content, oxygen demand, chemical compounds, heavy metals, and mineralogy. There is a need to determine the potential for salt water intrusion into the lake and the associated repercussions for aquatic life, drinking and irrigation.
- Estimate changes that might occur in the hydrology and morphology of the San Juan and Punta Gorda rivers and determine how these rivers will function with reduced flows; and monitor lake quality in comparison to past and current research information.

Biodiversity and Ecosystems

- Environmental Impact Assessment of the proposed new Lake Atlanta, specifically its impact on Caribbean Coast biodiversity. Run projections studies on species that might become established there and design precautionary measures to detect invasive species in general, including areas neighboring the many planned highways.
- Identify species threatened with extinction by the canal and determine the degree to which the physical barrier presented by the canal may inhibit animal movement and gene flow along the Mesoamerican Corridor.
- Identify secondary effects on biodiversity caused by human population movement, particularly those caused by resettlement in protected areas.

Socio-Economic and National Development Issues

- Determine the economic feasibility of the project by estimating the projected revenue from the canal in relation to the interest in capital payments, should the final construction costs be higher than the current estimate of US$50 billion.
- Is the economic value of Lake Cocibolca higher for navigation than for alternative uses?
- Will traditional land and water rights of Indigenous Peoples and Afro-descendent communities be differentially impacted and will the project observe all relevant legislation related to their autonomy?
- Will the Project consider the impacts on displaced populations and resources for those whose land has been expropriated?
- Will the Project observe the UN Declaration on the Rights of Indigenous Peoples as to "prior, free and informed consent"?

Implications. Construction of the canal's subprojects has begun apparently without independent assessments of economic, environmental, and social impacts. This lack of adherence to international best practices puts Nicaragua severely at risk for environmental and social damage that cannot be easily remedied. Accentuating the risk, the HKND

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Box 2. Are Safety Engineering Plans up to Required Standards?

- Have the canal and critical infrastructure and ancillary work been designed to remain intact under extreme loading conditions? Have the seismic, eolic, volcanic, and any other pertinent environmental loads been properly characterized in terms of nonexceedance probabilities or return periods?
- Has a transparent and rigorous Peer Review Process been implemented to ensure the highest practical quality standards during all aspects of conceptual work and design, construction and operation?
- Does the proposal specify robust systems for managing energy, water and environmental impacts, storm and flood controls, and mitigation of water shortages during droughts with adequate storage?

Box 3. Considering Alternative Routes

Canal planners originally considered six possible routes, all of them traversing Lake Cocibolca. In the final selected route, the 173-mile interoceanic canal enters Nicaragua 15 km north of Punta Gorda River on the Caribbean coast, cutting across Lake Cocibolca, and exits to the Pacific Ocean through Brito River. Since the lake is an important drinking water source, especially vital for a future with uncertain water sustainability, the ideal route would avoid the lake entirely. Would Project planners consider an alternative canal route bypassing Lake Cocibolca? This would allow the canal to obtain water from both Lake Cocibolca and Lake Xolotlán without contaminating these indispensable bodies of water. This was one of the original proposals for the Nicaraguan interoceanic canal.[39]

Group is guaranteed by Nicaraguan Canal Law 840 to be exempt from responsibility for "pre-existing environmental conditions," without defining such conditions. Likewise, no method is in place to determine how responsibility will be attributed for environmental damages subsequently caused by the construction.[38]

The Government should immediately devise an action plan to overcome assessment deficiencies to date. The action plan should include (1) immediate public access to critical technical data amassed by HKND Group, the Government, and their consultants; (2) formation of an international advisory board comprised of independent experts in the technical, economic, and social aspects of the project; (3) formation of a national stakeholder board, and (4) open information forums and free-flowing public debate.

Such an action plan will make it possible for Nicaragua to address the tensions between the putative economic benefits of the canal versus the risks of environmental and social disruptions. By taking swift action, the Nicaraguan government will become an example of how to balance development needs, conservation, and human rights. The science and technology communities can contribute to these sustainable development efforts by supplying scientific support to Nicaragua.

AUTHOR INFORMATION

Corresponding Authors

*(J.A.H.-P.) E-mail: jorgehuete@uca-cbm.org.
*(P.J.J.A.) E-mail: Alvarez@rice.edu.

Notes

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REFERENCES

(1) Concession and Implementation Framework Agreement for the Nicaragua Canal and Development Projects. http://www.pgr.gob.ni/PDF/2013/GACETAS/JUNIO/GACETA_111_17-06-2013.pdf (accessed February 22, 2015).

(2) Klytchnikova, I. I.; Cestti, R. E.; Escurra, J. J.; Pagiola, S. P. *Policy and investment priorities to reduce environmental degradation of the Lake Cocibolca watershed (Cocibolca): addressing key environmental challenges*. Latin America and Caribbean Region Environment and Water Resources occasional paper series. Washington DC; World 2013Bank. http://documents.worldbank.org/curated/en/2013/01/17617786/policy-investment-priorities-reduce-environmental-degradation-lake-nicaragua-watershed-cocibolca-addressing-key-environmental-challenges (accessed February 22, 2015).

(3) *Nicaragua Canal Project Description*. 2014. http://hknd-group.com/upload/pdf/20150105/Nicaragua_Canal_Project_Description_EN.pdf (accessed February 22, 2015).

(4) Alliance of Leading Environmental Researchers and Thinkers ALERT, November 7, 2014. http://alert-conservation.org/issues-research-highlights/2014/11/7/neotropical-rainforests-under-assault-from-infrastructure-mining (accessed February 22, 2015).

(5) Campos, V. The canal will irreversibly damage Lake Cocibolca. *Envío* 384. Jul **2013**. http://www.envio.org.ni/articulo/4726.

(6) Thorson, T. B. The impact of commercial exploitation on sawfish and shark populations in Lake Nicaragua. *Fisheries* **1982**, *7* (2), 2−10.

(7) Bussing, W. A. *Astyanax cocibolca*, a new characid (Pisces: Ostariophysi) from Lake Nicaragua, Central America. *Rev. Biol. Trop.* **2008**, *56* (3), 1361−1370.

(8) Kreft, S.; Eckstein, D.; Junghans, L.; Kerestan C.; Hagen U. Global Climate Risk Index 2015. Brief paper for Germanwatch. Berlin, 2014; http://germanwatch.org/en/download/10333.pdf.

(9) Huete-Pérez, J. A.; Tundisi, J. G.; Alvarez, P. J. J. Will Nicaragua's interoceanic canal result in an environmental catastrophe for Central America? *Environ. Sci. Technol.* **2013**, *47* (23), 13217−13219.

(10) Montenegro, S. G. *Informe final del evento de peces muertos de Septiembre 2004, en la Isla de Ometepe, Lago Cocibolca*; Ministerio del Ambiente y Recursos Naturales (MARENA), 2004.

(11) Jeppesen, E.; Jensen, J. P.; Søndergaard, M.; Lauridsen, T. L. Trophic dynamics in turbid and Clearwater lakes with special emphasis on the role of zooplankton for water clarity. *Hydrobiologia* **1999**, *408/409*, 217−231.

(12) Lane, O. P.; Arendt W. J.; Tórrez, Marvin A. Gámez Castellón, J. C. Pilot assessment of mercury exposure in selected biota from the lowlands of Nicaragua *Mesoamericana* August **2013**, *17* (1), 19−28. http://data.fs.usda.gov/research/pubs/iitf/ja_iitf_2013_Lane001.pdf].

(13) *Forest Losses and Gains: Where Do We Stand?*; United Nations Environment Programme: Vital Forest, 2009; http://www.unep.org/vitalforest/Report/VFG-02-Forest-losses-and-gains.pdf.

(14) *Global Forest Resources Assessment*. FAO. 2010.

(15) U.S. Fish and Wildlife Service. *Birds of Conservation Concern 2008*; United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management: Arlington, VA, 2008; http://www.fws.gov/migratorybirds/.

(16) Mendoza Aldana, Jose (2010) *Rapid Assessment of Drinking-Water Quality in the Republic of Nicaragua Country Report. © World*

DOI: 10.1021/acs.est.5b00215
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

Health Organization and UNICEF 2010. http://www.wssinfo.org/fileadmin/user_upload/resources/RADWQ_Nicaragua.pdf.
(17) Velásquez, L. E. *Manual Para Reconocer Los Recursos Pesqueros De Ometepe Y Principales Leyes Que Les atañen*; INPESCA: Nicaragua, 2008; pp 1−20.
(18) Zapata, M. J.; Hall, C. M.; Lindo, P.; Vanderschaeghe, M. Can community-based tourism contribute to development and poverty alleviation? Lessons from Nicaragua. *Curr. Issues Tourism* **2011**, *14* (8), 725−749.
(19) Weaver, P. L.; Lombardo, D. M.; Martinez Sánchez, J. C. *Biodiversity and Tropical Forest Conservation, Protection and Management in Nicaragua: Assessment and Recommendations*, Evaluation performed for USAID/Nicaragua, 2003.
(20) Barany, M. E.; Hammett, A. L.; Shillington, L. J.; Murphy, B. R. The role of private wildlife reserves in Nicaragua's emerging ecotourism industry. *J. Sustainable Tourism.* **2001**, *9* (2), 95−110.
(21) McCrary, Jeffrey K.; Young, D. P. New and noteworthy observations of raptors in southward migration in Nicaragua. *Ornitología Neotropical* **2008**, *19* (4), 573−580.
(22) Gollasch. S.; Galil, B.; Cohen, A. *Bridging Divides*, Maritime Canals as Invasion Corridors Series: Monographiae Biologicae, 2006; Vol. *83*. XIV, 316 p.
(23) Mumby, P. J.; Edwards, A. J.; Arias-González, J. E.; Lindeman, K. C.; Blackwell, P. G.; Gall, A.; Gorczynska, M. I.; et al. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature* **2004**, *427* (6974), 533−536.
(24) Urquhart, G. R. *Disturbance and Regeneration of Swamp Forests in Nicaragua: Evidence from Ecology and Paleoecology*; University of Michigan, 1997.
(25) Ellison, A. M. Wetlands of Central America. *Wetlands Ecol. Manage.* **2004**, *12* (1), 3−55.
(26) Mortimer, J. A. The feeding ecology of the West Caribbean Green Turtle (*Chelonia midas*) in Nicaragua. *Biotropica* **1981**, *13* (1), 49−58.
(27) Valiela, I.; Bowen, J. L.; York, J. K. Mangrove forests: One of the world's threatened major tropical environments. *BioScience* **2001**, *51* (10), 807−815.
(28) Mazda, Y.; Magi, M.; Kogo, M.; Hong, P. N. Mangroves as a coastal protection from waves in the Tong Kong delta, Vietnam. *Mangroves Salt Marshes* **1997**, *1*, 127−135.
(29) Reaka-Kudla, M. L. Biodiversity of Caribbean coral reefs. In *Caribbean Marine Biodiversity: The Known and the Unknown*; Miloslavich, P.; Klein, E., Eds.; DEStech Publications: Lancaster, PA, 2005; pp 259−276.
(30) Erwin, P. M.; López-Legentil, S.; Schuhmann, P. W. The pharmaceutical value of marine biodiversity for anti-cancer drug discovery. *Ecol. Econ.* **2010**, *70*, 445−451.
(31) Dengming, W. *An Investigation into Wastewater Treatment in the Three Gorges Reservoir Basin*. Probe International. 2013. http://probeinternational.org/library/wp-content/uploads/2013/02/WDMFebruary2013.pdf. (accessed January 8, 2015).
(32) The IUCN Red List for Threatened Species Home Page http://www.iucnredlist.org/ (accessed February 22, 2015).
(33) Meyer, A.; Huete-Perez, J. A. Conservation: Nicaragua Canal could wreak environmental ruin. *Nature.* **2014**, *506*, 287−289.
(34) Smith, L. C.; Stephenson, S. R. New Trans-Arctic shipping routes navigable by midcentury. *Proc. Natl. Acad. Sci. (PNAS Plus).* **2013**, DOI: 10.1073/pnas.1214212110.
(35) Centro Humboldt. *Valoraciones Socio ambientales de la ruta del canal interoceánico 2014*. 2014. http://www.confidencial.com.ni/downloads/355.pdf (accessed February 22, 2015).
(36) Antkowiak, T. *International Human Rights Clinic joins fight to stop Nicaragua canal*. 2014. http://www.law.seattleu.edu/news-and-features/news/2014-news-archives/international-human-rights-clinic-joins-fight-to-stop-nicaragua-canal.
(37) Acosta, M. L. *El canal y los pueblos indígenas*.2014. http://www.confidencial.com.ni/articulo/19683/el-canal-y-los-pueblos-indigenas. (accessed January 8, 2015).
(38) López, M. Truths about the canal concession all Nicaraguans should know. *Envío* 390. January **2014**.http://www.envio.org.ni/articulo/4805.
(39) Van Der Post, J. The interoceanic canal: An ever-present but never realized dream. *Envío* 396. July **2014**. http://www.envio.org.ni/articulo/4883.

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