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Critical Uncertainties and Gaps in the Environmental- and Social-Impact Assessment of the Proposed Interoceanic Canal through Nicaragua

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The proposed interoceanic canal will connect the Caribbean Sea with the Pacific Ocean, traversing Lake Nicaragua, the major freshwater reservoir in Central America. If completed, the canal would be the largest infrastructure-related excavation project on Earth. In November 2015, the Nicaraguan government approved an environmental and social impact assessment (ESIA) for the canal. A group of international experts participated in a workshop organized by the Academy of Sciences of Nicaragua to review this ESIA. The group concluded that the ESIA does not meet international standards; essential information is lacking regarding the potential impacts on the lake, freshwater and marine environments, and biodiversity. The ESIA presents an inadequate assessment of natural hazards and socioeconomic disruptions. The panel recommends that work on the canal project be suspended until an appropriate ESIA is completed. The project should be resumed only if it is demonstrated to be economically feasible, environmentally acceptable, and socially beneficial.

Keywords: Nicaragua, interoceanic canal, environmental impacts, social impacts, Lake Nicaragua

In June 2013, the Nicaraguan government approved a 50-year concession (renewable for another 50 years) to the Hong Kong Nicaragua Canal Development (HKND) Investment Company to construct an interoceanic canal across Nicaragua. The concession grants sole rights to HKND to plan, design, build, and subsequently operate the canal. In addition, it allows the construction of two ports, a free-trade zone, tourist resorts, an international airport, a power station, cement and steel factories, and other facilities. HKND plans to build the 276-kilometer (km) canal—over three times longer than, twice as wide as, and deeper than the Panama Canal—in 5 years. Excavation would remove approximately 5 billion square meters (m^3) of material, including 715 million m^3 of lake sediments (ERM 2015). The proposed route of the canal will have significant impacts on protected natural areas and indigenous lands (figure 1).

Construction and operation of the canal would require initial and frequent maintenance dredging of a canal 29 meters (m) deep across 107 km of the southern end of Lake Nicaragua (figure 1). The total volume of excavated material would be larger than in any previous civil infrastructure project. It would also be the largest wet excavation ever. To put the project in perspective, it would require about 980 million m^3 of marine and freshwater dredging (ERM 2015), about five times greater than the 197 million m^3 excavated to make the Hong Kong harbor (Syvitski and Kettner 2011). Significant impacts are likely on Lake Nicaragua, affecting 93,800 hectares (ha) of terrestrial

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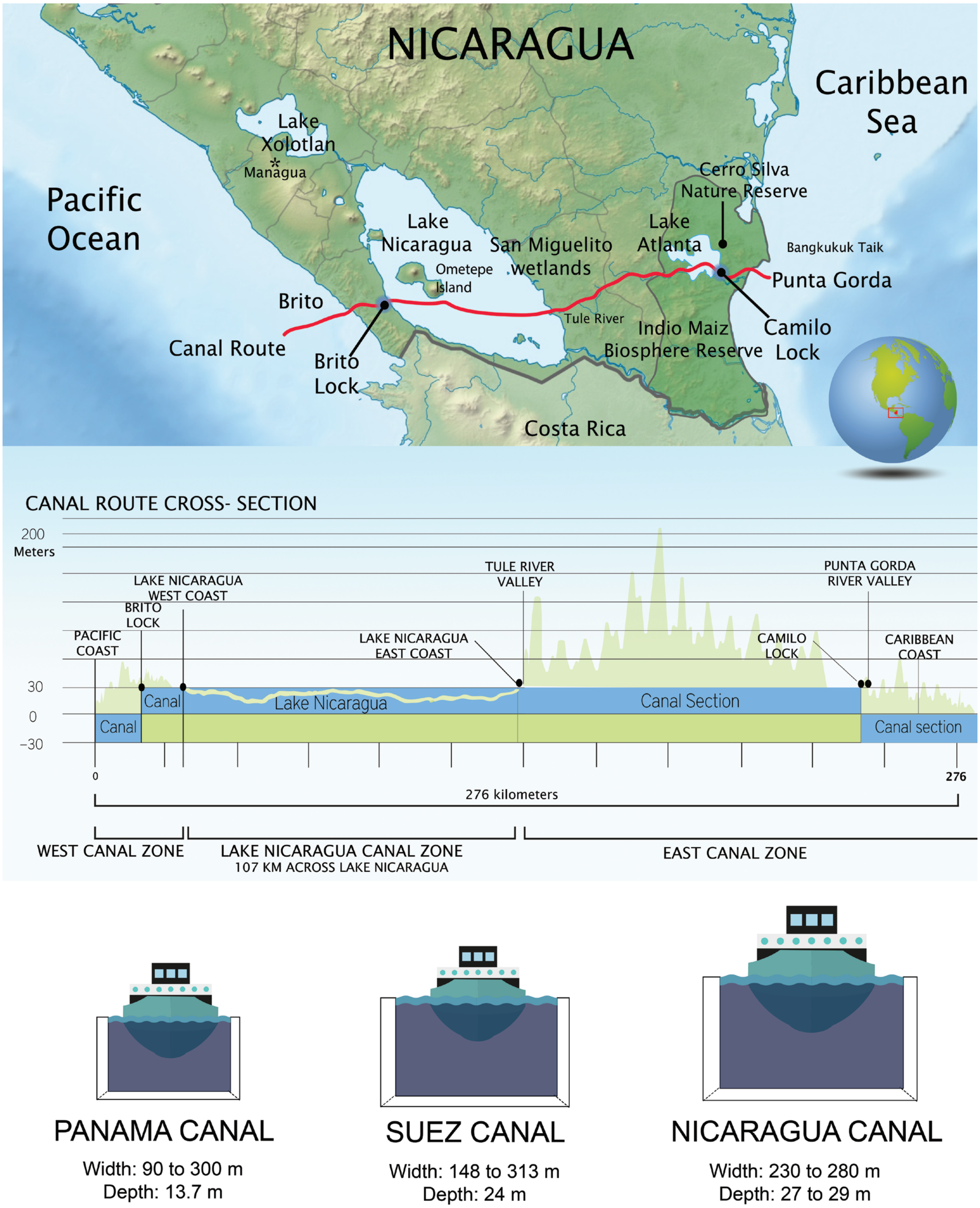

Figure 1. A proposed canal route for the Interoceanic Canal through Nicaragua. The canal would extend from the Pacific coast up the Rio Brito valley, over the continental divide, and down the Rio Las Lajas valley to Lake Nicaragua (also known as Lake Cocibolca). It would continue through the lake to south of the San Miguelito wetlands in the eastern side of the lake. From there, it would move up the Tule River valley and over the Caribbean highlands through the Cerro Silva and Indio Maiz nature reserves, ending in the Caribbean near the mouth of the Punta Gorda River (ERM 2015). Lake Nicaragua is very shallow, with an average water depth of approximately 9 meters (m), but the canal cross-section would have minimal depths ranging from 26.9 m to 29.0 m and minimum bottom widths ranging from 230 to 280 m. Construction would require extensive dredging and disposal or storage of large amounts of sediments and diminish water quality in the lake (ERM 2015). A comparison of the Nicaragua canal with the new sizes of the expanded Suez and Panama canals is provided. A large reservoir (Lake Atlanta) would be constructed to provide fresh water for operating the locks in the eastern section, flooding much of the Punta Gorda watershed. Illustration: Catalina Solano (used with permission).

ecosystems and 18,800 ha of tropical rainforest in the Mesoamerican Biological Corridor, as well as the displacement of over 30,000 people.

The no-bid concession was granted without an environmental assessment, public consultation, or consent from the autonomous indigenous peoples affected by the project. In November 2015, the Nicaraguan government issued an environmental permit to begin construction of the canal project after receiving an environmental and social impact assessment (ESIA) prepared in 18 months by Environmental Resources Management (ERM), an international consulting firm contracted by HKND. The Academy of Sciences of Nicaragua organized an international workshop to evaluate the ESIA report (ERM 2015) and to recommend additional steps needed to bring the ESIA process into conformity with the guidelines issued by the United Nations Conference on Environment and Development (UNCED 1992), the International Association for Impact Assessment (IAIA 1999), and the Equator Principles Financial Institutions (EPFI 2013).

The workshop participants raised serious concerns about the ESIA's insufficient data and analyses of the project's impacts on freshwater, terrestrial, coastal, and marine habitats, as well as on biological and human communities. The panel is particularly concerned about the risk of immediate and irreversible impacts from canal construction and operation on Lake Nicaragua. This lake is the country's main freshwater reservoir, and it is a unique ecosystem and an essential habitat for endemic cichlid fishes (Muschick et al. 2011) and numerous other species. The canal area is home to many protected species, including 20 terrestrial mammals, 53 bird species, 16 reptiles and amphibians, and 8 fish species—all subject to direct impact by the canal (table 1). Nicaragua's Pacific and Caribbean coasts also include coral reefs and endangered marine life (Guzman et al. 2008). These biologically diverse ecosystems provide important economic benefits, such as drinking water, food, ecotourism, and transportation, all of which will be affected by dredging, resuspension of sediments, increased salinity, and possible ballast-water leakage or discharge and man-made barriers in Lake Nicaragua and adjacent rivers (Huete-Pérez et al. 2015). The canal would traverse an area of documented seismic and volcanic activity (e.g., Funk et al. 2009). The region is also frequently exposed to extreme events, such as prolonged droughts, wildfires, hurricanes, tropical storms, and landslides (e.g., Leiva and Shankar 2001, Holt-Giménez 2002, Granzow de la Cerda et al. 2012). Intense rainfall and seismic activity along newly formed, steeply sloping terrain increase landslides and soil erosion (Devoli et al. 2007). These events also would increase the need for continued dredging to operate the canal.

The expert panel assembled by the Academy of Sciences of Nicaragua consolidated its discussions around five general topics: water and sediments, biodiversity, natural hazards and risks, social and economic implications, and international standards.

Water and sediments

Lake Nicaragua (also known as Lake Cocibolca) is the largest lake in Central America and the twentieth largest globally, covering 8144 square kilometers (km^2; Schwoerbel 1987). Overall, 60% of the lake has less than 9 m of depth, 37% is between 9 m and 15 m, and only 3% of its area is more than 15 m deep (INFONAC 1972). The current water quality of Lake Nicaragua makes it sufficient for drinking water and irrigation (CIRA 2007, 2012). Its productivity is classified as between mesotrophic and eutrophic (CIRA 2012). Currently, some communities, such as Juigalpa and San Juan del Sur, receive their drinking water (after treatment) from the lake. Other water projects for municipal urban areas (e.g., Granada and Cárdenas) are in the planning process. Even though many communities depend on rivers and Lake Nicaragua for irrigation and municipal water supplies, the canal concession allows water to be diverted from any river for canal operation. The impact of construction and consequent release of nutrients and other contaminants into the water may significantly lower water quality and add to municipal water-treatment costs. Lower water quality would affect future use and may also result in irreversible loss of species with potential economic consequences for fisheries production.

Water balance. The regional water balance strongly affects the water level within Lake Nicaragua, discharge in the San Juan River, and the ability to control salinization and the effects of soil erosion and nutrient loading to the lake. The canal would divert most of the discharge from the Punta Gorda River, which presently flows to the Caribbean, into Lake Nicaragua. The ESIA claims this would be sufficient for operating the Pacific and Caribbean locks. However, discharge in the Punta Gorda River was not measured by ERM and was simply estimated on the basis of extrapolation from other rivers. Tributary inputs to Lake Nicaragua used for lake circulation and salinity modeling were also extrapolated from a single discharge record on one tributary to the lake. A large reservoir on the canal route (Lake Atlanta; figure 1) and another, separate hydropower or storage reservoir will further alter the regional water balance. The large surface areas of the reservoirs will increase evaporative losses, especially during dry El Nino years. Combined with water withdrawal from Lake Nicaragua for lock operation, this could affect the water quantity and quality of the lake and could also limit the ability to maintain minimum ecological flows in the Punta Gorda River downstream from Lake Atlanta. Without an accurate estimate of river discharge in the Punta Gorda River and for the main tributaries to Lake Nicaragua, it is impossible to predict whether the diverted flow will be sufficient for lock operation and for minimizing long-term salinization of Lake Nicaragua. Furthermore, although climate change was considered in the ESIA, the water-balance analysis focused only on results from one model through 2070. It is also unclear how changes in temperature and precipitation were translated to changes in runoff and

Table 1a. The mammal (20) species with protected status found in the canal zone (ERM 2015, volume 12).

Scientific Name	Common Name	Level of Protection
Tamandua mexicana	Northern Tamandua (anteater)	International
Panthera onca	Jaguar	International
Choloepus hoffmanni	Hoffmann's two-toed sloth	International
Bradypus variegatus	Brown-throated three-toed sloth	International
Cebus capucinus	White-faced monkey	International
Alouatta palliata	Mantled howler monkey	International
Ateles geoffroyi	Geoffroy's spider monkey	International
Agouti paca	Lowland paca	National
Dasyprocta punctata	Central American Agouti	National
Potos flavus	Kinkajou	International
Nasua narica	White-nosed coati	International
Puma concolor	Puma	International
Leopardus pardalis	Ocelot	International
Leopardus wiedii	Margay	International
Puma yaguarondi	Jaguarunid	International
Dasypus novemcintus	Nine-banded armadillo	National
Odocoileus virginiana	White-tailed deer	National
Tapirus bairdii	Baird's tapir	International
Tayassu pecari	White-lipped peccary	National
Trichechus manatus	West Indian Manatee	International

Table 1b. The bird (53) species with protected status found in the canal zone (ERM 2015, volume 12).

Scientific Name	Common Name	Level of Protection
Dendrocynga autumnalis	Black-bellied whistling duck	National
Cairina moschata	Muscovy duck	National
Ortalis vetula	Plain chachalaca	National
Crypturellus soui	Little tinamou	National
Tinamus major	Great tinamou	National
Pteroglossur torquatus	Collared aracari	International
Ramphastos sulfuratus	Keel-billed toucan	International
Ara ambiguus	Great green macaw	International
Ara macao	Scarlet macaw	International
Amazona albifrons	White-fronted amazon	International
Amazona auropalliata	Yellow-naped amazon	International
Amazona autumnalis	Red-lored amazon	International
Pionus senilis	White-crowned parrot	International
Amazona farinosa	Mearly amazon	International
Aratinga finschi	Finsch's parakeet	International
Aratinga nana	Olive-throated parakeet	International
Aratinga canicularis	Orange-fronted parakeet	International
Brotogeris jugularis	Orange-chinned parakeet	International
Laterallus albigularis	White-throated crake	National
Aramides cajanea	Gray-necked wood rail	National
Platalea ajaja	Roseate spoonbill	International
Burhinus bistriatus	Double-striped thick-knee	International
Thalasseus elegans	Elegant tern	International
Ardea alba	Great egret	International
Ardea herodias	Great blue heron	International
Mesembrinbis cayennensis	Green ibis	International

Table 1b. (Continued).

Scientific Name	Common Name	Level of Protection
Sarcoramphus papa	King vulture	International
Pandion haliaetus	Osprey	International
Accipiter superciliosus	Tiny hawk	International
Leptodon cayanensis	Gray-headed kite	International
Elanoides forficatus	Swallow-tailed kite	International
Ictinia plumbea	Plumbeous kite	International
Geranospiza caerulescens	Crane hawk	International
Buteo magnirostris	Roadside hawk	International
Buteo platypterus	Broad-winged hawk	International
Buteo nitidus	Gray-lined hawk	International
Buteo swainsoni	Swainson's hawk	International
Buteo albicaudatus	White-tailed hawk	International
Parabuteo unicinctus	Harris hawk	International
Busarellus nigricolis	Black-collared hawk	International
Elanus leucurus	White-tailed hawk	International
Chondrohierax uncinatus	Hook-billed kite	International
Caracara cheriway	Crested caracara	International
Herpetotheres cachinnas	Laughing falcon	International
Falco rufigularis	Bat falcon	International
Falco sparverrius	American kestrel	International
Falco peregrinus	Peregrine falcon	International
Porphyrio martinicus	Purple gallinule	International
Gallinula chloropus	Common moorhen	International
Aphanotriccus capitalis	Tawny-chested flycatcher	International
Turdus grayi	Clay-colored thrush	National
Quiscalus nicaraguensis	Nicaraguan grackle	International
Icterus galbula	Baltimore oriole	National

Table 1c. The amphibian (3) species with protected status found in the canal zone (ERM 2015, volume 12).

Scientific Name	Common Name	Level of Protection
Agalychnis callidryas	Red-eyed tree frog	National
Dendrobates auratus	Green-and-black poison frog	National, International
Oophaga pumilio	Strawberry poison frog	National, International

Table 1d. The reptile (13) species with protected status found in the canal zone (ERM 2015, volume 12).

Scientific Name	Common Name	Level of Protection
Chelonia mydas	Green sea turtle	National, International
Iguana iguana	Green iguana	National
Ctenosaura smilis	Black iguana	National
Basiliscus plumifrons	Double-crested basilisk	National
Basiliscus vittatus	Brown basilisk	National
Lepidochelys olivacea	Olive Ridley sea turtle	International
Crocodylus acutus	American crocodile	International
Caiman crocodilus	Spectacled caiman	National
Kinosternon scorpioides	Scorpion mud turtle	National
Rhinoclemmys annulata	Brown wood turtle	National
Rhinoclemmys funerea	Black river turtle	National
Boa constrictor	Common boa	National
Lampropeltis triangulum	Milk snake	National

Table 1e. The fish (8 species with protected status found in the canal zone (ERM 2015, volume 12).

Scientific Name	Common Name	Level of Protection
Pristis perotteti	Large-tooth sawfish	International
Pristis pectinata	Small-tooth sawfish	International
Carcharhinus leucas	Bull shark	International
Atractosteus tropicus	Tropical gar	National
Centropomus pectinatus	Tarpon snook	National
Megalops atlanticus	Atlantic tarpon	National
Thunnus obesus	Big-eye tuna	National, International
Thunnus albacares	Yellow fin	National, International

Table 1f. The invertebrate (5) species with protected status found in the canal zone (ERM 2015, volume 12).

Scientific Name	Common Name	Level of Protection
Anadara similis	Ark cockle	National
Anadara tuberculosa	Pustulose ark	National
Macrobranchium spp.	Bigclaw river shrimp	National
Penaeus stylirostris	Blue shrimp	National
Penaeus vannamei	Whiteleg shrimp	National

evaporation rates or even whether decreased discharge simulated for the Punta Gorda River was incorporated into the water balance for the whole lake circulation and salinity model. If drought duration and frequency increase as is predicted by current climate models, the biological diversity of the rivers and surrounding rainforests as well as the capacity to operate the canal effectively and efficiently may be greatly affected.

The workshop participants identified several fundamental weaknesses in the ESIA and shared the many concerns raised by ERM. According to the ESIA, "a comprehensive water balance should be completed that closes the following gaps: an updated, detailed bathymetric survey of Lake Nicaragua (including the frequently inundated lake shore areas), analysis at daily time scale (stream flow, evapotranspiration, and lake level), updated rating curve for the San Juan River outflow, updated evaluation of evapotranspiration from the frequently inundated shoreline areas, projected increased water consumption, and the effects of climate change, especially drought conditions." The ESIA also pointed out that "HKND should prepare an updated and more comprehensive water balance to confirm the results of the preliminary studies and the adequacy of water supply for Project operations without impacting water levels in Lake Nicaragua" (ERM 2015). HKND has not demonstrated that water levels—as well as water quantity and quality in the lake and in the San Juan River—can be sustained.

Salinity. The operation of the canal could alter the physical and chemical properties of freshwater habitats. Because seawater is likely to enter the lake during canal operation, the salinity and density stratification of Lake Nicaragua will increase over time. The density stratification of some deeper sections of the lake will lead to deoxygenation and the loss of habitat for fish and other key components of the lake food web. The ESIA included a projected increase of 500-milligrams-per-liter salinity in the lake, enough to jeopardize its use for irrigation and potable water (because of exceeding the secondary standard for total dissolved solids) and for affecting the food web's plankton and benthic organisms. The ESIA notes that "HKND should identify the specific salinity mitigation measures it would propose and re-evaluate the potential for salinity impacts." The workshop participants concluded that additional analysis should describe how salinity will be controlled in the canal and in Lake Nicaragua, and it must include a calibrated and validated salinity model that accounts for lake dynamics.

Sediment re-suspension and eutrophication. The massive excavation and dredging during construction and operation would likely lead to altered nutrient concentrations, lower levels of dissolved oxygen, increased turbidity, and the possible growth of toxic algal and cyanobacterial blooms in Lake Cocibolca. These impacts will likely be exacerbated by high wind velocity across the lake. Dredging would further disturb large quantities of lake sediments, affecting water transparency. The resulting reduction in light penetration into the water column would reduce primary production by diatoms and other algae that sustain the fisheries and native species. This mixing of sediments, toxins, and nutrients would affect the lake's ability to serve as a drinking-water and irrigation supply and to support fisheries and provide habitat for numerous freshwater species. According to the ESIA, high concentrations of arsenic, mercury, and pesticide concentrations are found in the sediments, underscoring the potential for increased contamination by proposed dredging activities (ERM 2015).

Multiple impacts on water quality resulting from sediment re-suspension and the mobilization of contaminants would occur throughout all phases of the project: from excavation and construction to operation (oil tanker and container traffic) and maintenance dredging. These incidents, exacerbated by potential incidental or accidental chemical releases from ships, could lead to the bioaccumulation of toxins in the biota. An analysis is needed of possible health hazards from the remobilization of arsenic, mercury, and pesticides; accelerated eutrophication due to release of nitrogen and phosphorus from sediments; fish kills resulting from deoxygenation and phytotoxin production from cyanobacterial blooms; and hydrocarbon spills during canal operation.

The last bathymetric study of Lake Nicaragua was undertaken in 1972 (INFONAC 1972). Since then, the watershed has undergone widespread deforestation and substantial increases in erosion, causing disproportionate sedimentation in the lake. An updated bathymetric evaluation of the entire lake using modern techniques is imperative. A thorough study of the sediments' characteristics and their stratigraphy based on numerous profiles of deep sediment cores distributed throughout the 107-km length of lake is needed to determine how much and how long dredging would be needed to construct and operate the canal. The ESIA presented results from only one profile of a shallow sediment core, which was in turn used by HKND for structural design plans. The ESIA noted that a "single lake core is inadequate to characterize sediment stratigraphy." The ESIA concluded that HKND must "conduct additional sediment borings and sampling in Lake Nicaragua to better characterize the stratigraphy of the sediments and their physical properties to confirm that the proposed dredging and disposal strategy would be effective." The analysis of a more complete sediment characterization could have "the potential to require changes to the canal design."

Plans for the deposition and storage of the extracted sediment material include the creation of a series of 40-km^2 islands within Lake Nicaragua. Sediment mounds are also planned parallel to the dredged channel in the lake and are to hold 75% of all dredged material from the lake. These mounds and islands will contain materials that are biologically, chemically, and physically active, with a high risk of contaminant release. Contaminant release during sediment resuspension should be studied. The dredging-management plan lacked sufficient information to evaluate likely impacts on water quality during initial and maintenance dredging in this frequently wind-mixed shallow lake. A complete study of lake hydrodynamics is needed and would most likely lead to changes in the canal design and construction.

The workshop participants recommend analyzing the effects of salinization and sedimentation from increased landslides on lake biota. The increased turbidity resulting from the initial dredging and maintenance operations to retain the required depth could alter the lake's food web. The re-suspension of nutrients and toxins in the sediments could alter algal growth as well as filter-feeding consumers (zooplankton) that form the basis of the lake's food chain. These food resources for fish would be diminished and could rapidly be replaced by massive blooms of cyanobacteria that are known to produce toxins for fishes and people.

Biodiversity and ecosystems

Direct and indirect impacts on biodiversity are especially important in highly diverse tropical regions where ecosystems face multiple threats (Gibson et al. 2011). The canal project presents potentially large and irreversible impacts on marine, freshwater, and terrestrial ecosystems threatening critical forests and wetlands, including the Cerro Silva and Indio Maiz nature reserves and the San Miguelito Ramsar wetlands (summarized in table 2). The immediate damage to these ecosystems could include loss of species and habitat connectivity. Major impacts on migratory species of freshwater species with complex amphidromous life cycles (e.g., *Macrobrachium carcinus*) are likely to result from the proposed dam construction and flooding within the Rio Punta Gorda drainage. Research on similar species in other tropical rivers has documented the need for these migratory species to have access to free-flowing rivers (e.g., McDowall 2007, Kikkert et al. 2009, Bauer 2013, Covich 2014). Fish migrations in and out of Lake Nicaragua through the Rio San Juan (e.g., Thorson 1982) might also be affected by the proposed dredging operations. Midas cichlids are endemic to Nicaragua's crater lakes (Mallet et al. 2009, Barluenga and Meyer 2010). Several species that live in Lake Nicaragua require a connection to the Atlantic and migrate up and down the San Juan River and other rivers. Among those are four species of snooks (*Centropomus ensiferus*, *nigrescent*, *parallelus*, *pectinous*), *Megaflops atlanticus*, the bull shark (*Carcharhinus leucas*), and the tropical gar (*Atractosteus tropics*). About 90 species are found in the San Juan and Punta Gorda River drainage systems. Approximately 30% are found in only one or the other, and only about 30% are found in both (Axel Meyer, Department of Biology, Konstanz University, Konstanz, Germany, personal communication, 15 April 2016). Impacts from the canal project would likely affect many species. Inundation of rainforest habitats and rivers during construction of Lake Atlanta (399 km^2) would destroy terrestrial ecosystems and eliminate riverine habitats for newly discovered endemic species of fishes and invertebrates in the Rio Punta Gorda watershed. This large water reservoir will provide the water to operate the locks for the canal system.

The ESIA quantifies the direct loss of ecosystems due to conversion for canal construction but does not assess the number of species lost or the breakdown in ecosystem function at a larger scale. From the influx of sediments into aquatic and marine ecosystems to the disruption of continuity in terrestrial, the potential for loss of ecosystem function is large (DeFries et al. 2004, Vaughn 2010). Instead of attempting to address potential side effects, the ESIA simply states "a larger portion" of habitat would be "indirectly impacted by the project." In table 2, we summarize the ESIA's

Table 2. Identifiable threats to ecosystems and biodiversity. The ESIA reports lowland rainforest, swamps, and middle and Caribbean slope rivers as those that would experience the most major impacts.

Ecosystem	Threats	Area/ River Length Directly Affected	Potential Area/Length Indirectly Affected	Key Species
Lowland Rain Forest	Habitat loss, fragmentation	524 ha Middle 18,800 ha Caribbean	62,780 ha Caribbean	Jaguar, Baird's Tapir, Great Green Macaw, Rosewood (*Dalberghia retusa*), 17 Endangered species
Tropical Dry Forest and Scrub	Habitat loss, fragmentation	2232 ha Pacific	5346 ha Pacific	Puma, Royal Cedar (*Cedrella odorata*)
Mangrove	Habitat loss, fragmentation	48 ha Brito		Waterbirds
Freshwater Wetland including San Miguelito RAMSAR Site	Habitat Loss, Changes in Hydrology	140 ha Middle 438 ha Caribbean		Jabiru, Neotropical Migrant Birds
Swamp	Habitat loss, fragmentation, complete removal	664 ha		*Raphia taedigera*, Baird's Tapir, Jaguar
Lake Nicaragua – Freshwater Lake	Suspension of sediments, spills, invasive species	196 km^2	7954 km^2	Cichlids, Aquatic Invertebrates, Plankton, Bacterial Communities
Rivers	Changes in hydrology, spills, invasive species, flooding	57.5 km Pacific 102.5 km Middle 968.5 km Caribbean		Cichlids, Poeciliids in Punta Gorda River drainage
Beach	Lighted development,			Green Sea Turtles
Coral Reef	Sedimentation, chemical pollution			Corals, Many Fish Species

Note: The 62,780-ha figure represents the loss of agricultural land and grassland in the canal path east of Lake Nicaragua, which would cause the displacement of ranchers and farmers. The historical pattern of agricultural colonists has been to move eastward into rainforest areas (Stevens et al. 2011). The majority of this potential impact would occur in the Indio Maiz, Cerro Silva, and Punta Gorda protected areas. The 5346 ha are for agricultural lands lost in the canal's western sector, resulting in the displacement of farmers and ranchers. Of the 94,000 hectares (ha) of terrestrial habitat loss, 65,000 ha of loss would occur within protected areas. Sources: ERM 2015, tables 7.3-3, 7.3-7, 7.3-9, 7.4-4, 7.4-10, and 7.4-14.

stated extent of potential direct and indirect loss of terrestrial and freshwater ecosystems.

Indirect ecosystem impacts can produce a cascade of effects resulting from losses of essential keystone species that maintain population balances (Dudgeon 2000, Wright 2005, Hadley et al. 2014). The long-term interruption of movements of numerous species of wildlife (figure 2) through the Mesoamerican Biological Corridor would disrupt migratory species and natural dispersal of populations that sustain genetic diversity (Harvey et al. 2008, DeClerck et al. 2010). Lake Atlanta reservoir construction would limit migratory species now using the Punta Gorda River drainage network to connect coastal and estuarine populations. Canal construction would rapidly displace many people and accelerate the migration of farmers into protected areas, intensifying deforestation and pressures on natural resources. The resulting deforestation and increased erosion would greatly affect the water quality and runoff to streams flowing into Lake Nicaragua (Carey et al. 2015). The sedimentation of downstream habitats would eliminate access to essential habitats needed for the reproduction of fish and invertebrates that help sustain the lake's fisheries and water quality (Vörösmarty and Sahagian 2000, Jones et al. 2012, Winemiller et al. 2014).

The canal project has significant impacts and repercussions not only for rivers, lakes, and wetlands but also for coastal marine ecosystems in the Caribbean Sea and Pacific Ocean. Sediment accumulation in estuarine environments and the continental shelf will change existing biochemical patterns, influencing nutrient cycling in the affected marine environment and disturbing primary production in estuarine and coastal waters (Reis-Filho and Alcantara-Santos 2014). These potential effects on fisheries need further research to assess their long-term ecological impact. The workshop participants concluded that the ESIA has serious shortcomings in the analysis of the impact of the proposed canal on biodiversity and ecosystems in Nicaragua.

Freshwater biodiversity. Freshwater habitats harbor exceptionally high levels of biodiversity (Hawksworth and Kalin-Arroyo 1995) and have a particularly high risk of losing biodiversity because of anthropogenic impacts (Dudgeon 2000, Sala et al. 2000). Canal construction threatens freshwater habitat quality and would most likely lead to habitat fragmentation, as well as invasion by nonnative species. The flooding of river catchments to create storage and hydropower reservoirs would irreversibly alter free-flowing rivers that provide essential habitats for endemic species. The canal also would connect currently separate freshwater habitats. Specifically, the Punta Gorda River and the San Juan River watersheds would be connected, which would drastically change the routes of dispersal and migration

Figure 2. A jaguar near the community of Punta Aguila (the indigenous name is Bankukuk Taik) captured by a camera trap installed by the Michigan State University. The location of the photograph is directly in the footprint of the canal. A jaguar was also photographed at the same location in 2014. Photograph: Gerald R. Urquhart.

for many species. An artificial connection of these watersheds would have potentially detrimental consequences for several species and families (e.g., Poeciliidae, Cichlidae, and Characidae), such as the hybridization of genetically distinct, locally adapted populations or extinction by species replacement. Either scenario would lead to the loss of unique genetic diversity.

The potential for impacts from invasive species related to canal construction and operation remain unstudied. For example, the devil fish, *Hypostomus panamensis*, represents a recent invasion of the San Juan River system and is disrupting the food web composed of native species.

Furthermore, construction of the canal could drastically increase the number of nonnative, invasive species associated with shipping and boat traffic (Muirhead et al. 2015). The potential for invasive parasites and competing nonnative fishes to disrupt the lake's food web is substantial (e.g., Smith and Bermingham 2005, Choudhury et al. 2013). No analyses of the impacts on subsistence and recreational fishing or the loss of native species were presented in the ESIA. Fishing, especially within Lake Nicaragua, constitutes an important livelihood for many Nicaraguans.

Marine biodiversity. The impact of the canal on marine biodiversity was inadequately addressed in the ESIA. The analysis focused on species lists and presence versus absence rather than the estimates of population densities needed to estimate the long-term viability of the many at-risk species. Insufficient information was provided by the ESIA to evaluate the methods of data collection and analysis for marine biodiversity. For instance, the ESIA included the results of sampling the marine benthic organisms from only one site on the Pacific coast in an estuarine habitat on the basis of a single sample in one season.

The ESIA did not consider the potential impacts of the new freshwater outflows into the Pacific marine environment relative to seasonal changes in salinity. To evaluate a project's impact on ecosystems, the relative importance of species interactions needs to be determined in terms of their contribution to food-web robustness (Gilarranz et al. 2016). Species interactions are crucial to the maintenance of marine biodiversity, and although the ESIA briefly acknowledges the role of plankton as the foundation of a food web, the potential impacts must be clearly elucidated.

The ESIA indicated that "mitigation will be implemented based on current international standards." However, for a project of this scale, mitigation will be extensive and must be integrated within a detailed plan to define requirements for protecting the affected ecosystems. There are several threats that could have serious negative consequences for the productivity of marine fisheries.

Terrestrial biodiversity. Project development will alter 93,800 ha of terrestrial ecosystems. Over 21,000 ha of the area are covered by broadleaf forest, including 18,800 ha of tropical rainforest in key segments of the Mesoamerican Biological Corridor. In the western terrestrial canal segment, 11 endangered (EN) and critically endangered (CR) species would be threatened by habitat loss and disturbance, and an additional 17 EN or CR species face similar threats (ERM 2015, table 7.5-1). On the Caribbean side of the canal, canal and subproject development would result in the loss of 664 ha of tropical swamp forest dominated by *Raphia taedigera*, considered a key habitat for endangered wildlife, including Baird's tapirs (*Tapirus bairdii*; Jordan and Urquhart 2013).

The ESIA concluded that "the project would unavoidably impact primary rainforest and the Punta Gorda River, which have biodiversity values which cannot be replaced" (ERM 2015). Although the ESIA indicated a need for additional long-term biodiversity studies, it focused on a list of species without analysis of population sizes, and extinction risks were not evaluated. The estimates of the terrestrial biodiversity of Pacific, Central, and Caribbean regions were based on only six sample locations in each region. The sampling of terrestrial mammals was based on camera trapping (limited

Figure 3. A view of Ometepe Island with its twin volcanoes illustrates the proximity of a major fault line to the canal route. Photograph: Andreas Härer.

to 190 camera-trap days) and detected less than 50% of the known species for the region (Jordan and Urquhart 2013, Jordan 2015). The mitigation measures suggested by ERM are unlikely to be useful for rebuilding forests or preventing substantial biodiversity loss.

Sustaining forest cover over long periods of time to respond to extremely variable rainfall is increasingly challenging given the uncertainty of climate-change impacts and the resulting movements of people affected by these natural disturbances, such as droughts and hurricanes (e.g., Wright et al. 2007, Condit 2015). During wet periods, even where forest cover is sustained, landslides and bank erosion accelerate during intense rainfall on steep terrain (Devoli et al. 2007). The loss of young trees and other vegetative cover during severe drought and associated wildfires sets up conditions for greater erosion during the next period of wet years (Granzow de la Cerda et al. 2012). Eastern Nicaragua is vulnerable to loss of forest given its geographic location and exposure to disturbances from tectonic events, tropical storms and hurricanes, and El Nino–related droughts and fires. Canal construction will exacerbate these disturbances; nevertheless, these dynamics were not addressed by the ESIA. Previous publications have recommended long-standing studies to assess biodiversity in the canal zone (Huete-Pérez et al. 2015). The necessity of long-term, systematic data on ecohydrologic and environmental impacts of canal construction is now well documented by numerous studies of the watershed and surrounding areas of rainforest habitats (e.g., Condit et al. 1995, 2001).

The ESIA asserts that the affected areas in the eastern section of the project are already undergoing rapid loss of forest cover and that the project, through mitigation, could "decelerate or even reverse these trends." However, it is not clear how international standards to protect forests can be ensured during construction given that there is no mechanism in place to evaluate whether the standards are met and because the Ministry of Environment (mandated for environmental issues) does not have the necessary human and institutional capacities. Ultimately, the ESIA concludes that the benefits of mitigation "must be tempered with the acknowledgement that the loss of primary rainforest … would have lasting significant adverse effects."

Natural hazards and risk management

Nicaragua is uniquely vulnerable to damage and loss from hurricanes and tropical storms. It ranks twenty-fifth in the world for the highest potential for high economic losses from natural hazards and thirtieth in earthquake vulnerability (ERM 2015). The ESIA recognized that HKND has not provided a formal hazard or risk study for the project although areas of concern include 22 tectonic faults along the canal route (ERM 2015). No analysis is provided on methodologies for risk management associated with fault movement and associated consequences. The proposed canal route also crosses a zone with a high risk of volcanic activity, crossing the lake just to the south of the twin volcanoes of Ometepe Island (figure 3), but the ESIA included only minimal analysis of volcanic impacts. Furthermore, the ESIA postulates tsunamis with a wave height of only 1.62 m, which is not historically accurate. During the tsunami of 1992, sections of Nicaragua's Pacific coast experienced waves up to 9 m high (SINAPRED 2005). Moreover, the ESIA does not consider the compounded possibility of volcanic activity and geological faulting resulting in tsunamis originating in and affecting Lake Nicaragua (SINAPRED 2005).

The ESIA noted that additional studies are required on the stability of steep slopes along the canal route. The slopes, above and below water, are exposed to seismic, hurricane, flood, and slide hazards. However, the ESIA did not provide a methodology to manage this risk, even though slope stability is extremely important for canal maintenance.

The workshop participants emphasized that studies on hazard risks must be conducted before final design or construction considerations are completed. The scale of the proposed canal and the obvious high-risk situation in Nicaragua require a much more in-depth and quantitative analysis.

Social and economic implications

One of the project's key impacts will be the physical displacement of human populations. The canal construction and operation would require temporary and permanent expropriation of approximately 2900 km^2 of land—about 2.3% of the total surface area of Nicaragua. Significant impacts will directly affect the livelihoods and well-being of at least 30,000 people. According to the ESIA, however, none of the information pertaining to resettlement planning has been made public to date. The ESIA states that, "at the time of this assessment the temporary resettlement areas were not identified, and therefore impacts could not be assessed and rated" (ERM 2015). Increased internal immigration could

Box 1. Key deficiencies of the ESIA's social-impact assessment.

- No quantification of populations indirectly affected is provided, and no specific data are considered for the economic displacement analyses. Mitigation measures are incompletely described and vague and therefore not reliable. The proposed mitigation measures would incur substantial costs that are not considered.
- No evaluation of the risk, magnitude, and cost of physical and/or economic displacement was conducted. Moreover, the field data are inadequate, and the risks and costs are not quantified. Quantifying the risks and costs should be paramount to an ESIA report.
- The social impacts for autonomous indigenous peoples are reduced to a mere list, and the social and cultural magnitudes of the canal project impacts are not considered in the analysis. Afro-descendant and indigenous peoples, including the Rama and Kriol communities residing within the project's eastern canal segment, will be significantly affected. They have a constitutional right to be consulted on major projects and policies that affect their rights and way of life, according to international best practices.

exacerbate already hostile interethnic conflicts for land, territorial control and natural resources.

Land expropriation and involuntary resettlement processes have not been set up to meet international standards. The ESIA states, "ERM is not aware of an official consent from the indigenous peoples affected by the Project" (ERM 2015), which violates Afro-Caribbean and indigenous and communities' land rights and autonomy. Box 1 describes some of the gaps in ESIA's social-impact assessment. More generally, the ESIA lacks an historical social dimension for physical and economic displacement. Considering Nicaragua's recent history of civil war, irregular immigration, and social and ethnic conflicts, emphasis must be given to the cultural heritage, human rights, and well-being of affected populations at every stage of the project.

With regard to the impact on the Nicaraguan economy, much of the construction materials and equipment—and half of the construction workers—will come from abroad. The large influx of capital into a small country during construction will cause a boom, but the end of this influx when construction is completed will cause a sharp downshift in economic activity, making for a difficult economic transition. When the canal is operating, it will create jobs and generate income in the sectors directly involved and in other supply and support sectors, but the extent to which this will occur is limited.

The direct impact on employment during the construction phase would not be significant (less than 1% of the national labor force will find new employment). Following construction, the employment opportunities created by the canal's operation are unlikely to keep pace with the natural growth of Nicaragua's labor force. The canal will have little impact on average productivity and is unlikely to pull the country out of poverty.

Another economic concern involves what has been called the Dutch disease. In a small, open economy such as Nicaragua's, the surge in domestic demand due to a large influx of capital during construction can raise domestic prices, especially for nontradable goods and services. This can have the effect of raising the real exchange rate and making other Nicaraguan exports such as tourism less competitive, which would be economically damaging.

These economic impacts are all noted by the ESIA, but they are not quantified. In order to make a meaningful assessment of the likely net impact on the Nicaraguan economy and balance of payments, a quantitative analysis is required—something that was done in Panama in 1966 when a new interoceanic canal was being considered there (CEPAL 1967). The requisite macroeconomic and general equilibrium models of the Nicaraguan economy exist, have been used by researchers investigating similar issues, and should have been used for the ESIA (Sánchez et al. 2008).

Economists also measure, in monetary terms, the value that people place on changes in the natural environment—known as *nonmarket valuation*. The ESIA applied this approach to some environmental impacts but not others. It did not value the impacts on water supply or fishing. It did value the loss of various types of habitat, but not in a manner that permitted a meaningful valuation of individual ecosystem services provided by these habitats (Vaughn 2010). Instead, it used highly generic values from two papers surveying the overall literature with limited relevance for the specific habitats in Nicaragua. The result is an absence of a meaningful measure of the nonmarket value of the environmental resources damaged by the canal.

International standards

The ESIA process must be carried out "while there is still an opportunity to modify (or, if appropriate, abandon the proposal)," (IAIA 1999). The decision by the Nicaraguan government to allow construction by HKND prior to a thorough ESIA undermines the intent of impact assessment and ignores best-practices principles exemplified by the 1999 Principles of Environmental Impact Assessment Best Practices (IAIA 1999).

The workshop participants concluded that at least 6 of the 14 best-practices principles from IAIA were significantly deficient in the ESIA: rigorous, relevant, adaptive, participative, credible, and transparent. The remaining principles are purposive, practical, cost effective, efficient, focused, interdisciplinary, integrated, and systematic.

Rigorous. The ESIA presents inadequate assessments in many areas, as we outlined in other parts of this article. Particularly egregious examples include lack of sediment cores for Lake Nicaragua, cursory mention of natural hazards, and minimal evaluation of impacts on native peoples.

Relevant. Information on decisionmaking is lacking in regard to mitigating impacts in all areas. Furthermore, the public has not been properly informed of the potential long-term damages and losses from the project and that its possible financial benefits may have been overstated.

Adaptive. The ESIA identifies no mechanisms for adaptive management, including obviously important mechanisms for water-quality monitoring and response, handling grievances, and mitigating loss of biodiversity.

Participative. The ESIA process to date has had minimal public participation in information gathering and interpretation. In May 2015, HKND formally submitted the ESIA to Nicaraguan authorities. However, it remained inaccessible to the public until November 2015, after government approval of the ESIA report (HKND 2015). Releasing the ESIA only after the "environmental permit" had been granted leaves no time for local scientists and the public to contribute and provide a meaningful response. The lack of information and opportunities for widespread public input during the 2 years of the project's development may explain in part why it has been so controversial and challenged in the courts by opponents.

Credible. The ESIA process has been largely a closed process carried out without independent review, with the exception of a 2-day ERM-sponsored meeting attended primarily by US experts who reviewed drafts of 4 chapters of the 14-volume environmental assessment. The socioeconomic aspects of the ESIA were not available for discussion. The meeting's conclusion was that ERM's environmental study contained significant gaps (FIU 2015). Although ERM responded to the critiques of that meeting in the final draft, the scope of the ESIA was not altered in a meaningful way given the limited time constraints. Following ESIA approval, local scientists, conservationists, and community leaders raised concerns about the procedural irregularities. Leaders of the country's indigenous and Afro-Caribbean communities maintain that government officials are coercing them to consent to the proposed canal passing through their autonomous territory.

Transparent. The ESIA process was carried out with limited opportunity for broad public or independent-expert input. Canal project planners unilaterally decided key factors, such as project location, design, operating procedures, and even the scope of their project's environmental and social-impact assessments. The evaluation process, as well as project implementation, would gain from being more transparent, being more socially inclusive, and allowing local communities' participation in the decisionmaking process. The transparency regarding the manner in which the project could harm or benefit local populations, including indigenous communities, and the legality of many aspects of the project have been strongly questioned.

The proposed Interoceanic Canal Project came into being in record time, and ERM's ESIA report, contracted directly by HKND, was likewise produced quickly—within an 18-month timeframe. This is an insufficient period to conduct thorough data collection and to interpret the findings and generate realistic mitigation strategies for a project of this scale. To avoid deleterious and costly mistakes—many irreversible—long-term studies providing high-quality baseline data must be performed well before a project begins construction. Therefore, the panel recommends that HKND must establish an insurance bond to cover all possible disasters, as is common international practice to insure contingent liabilities (Cardenas et al. 2007). This bond is particularly important given that HKND has been reported to create a consortium of 15 associated companies spread over China, Netherlands, Caiman Islands, and Nicaragua (Enríquez et al. 2014), which would diminish HKND's liability and hinder Nicaragua's ability to fully recuperate the costs of recovering from a disaster.

The ESIA concludes that "there are several areas where the project cannot meet these [international] standards" and points out many risks and gaps it could not address in the time provided. The ESIA also acknowledges that the project has many risks. In the Project Description, the ESIA affirms that "all routes for a Canal de Nicaragua through the Study Area would have significant environmental and social impacts, as essentially all of the economically feasible routes would need to traverse internationally recognized protected areas, legally recognized indigenous lands, and Lake Nicaragua, all of which under normal situations would be considered no-go areas" (ERM 2015).

Megaprojects such as this typically require many years of assessment and planning to determine their feasibility and to design appropriate mitigation measures. For instance, a sea-level canal proposed for Darien, Panama, required a 10-year study before being abandoned in the 1970s as unfeasible (Covich 2015). The construction of China's Three Gorges Dam, which proceeded on the basis of an ESIA of scope and study time similar to those of the report presented by ERM for the canal through Nicaragua, has since become a prime example of the unanticipated environmental costs of rushed megaprojects (Stone 2011): frequent landslides, water pollution, and increased seismic activity. There are many lessons learned from the environmental impacts of large construction projects within China, such as the upstream and downstream effects of creating a large reservoir (Park et al. 2003, Wu et al. 2004, Yang and Lu 2013). More than a million people were relocated at the beginning of the project, and more than four million people will have to be relocated by 2020, resulting in more than double the official cost of the project (Stone 2008). As the long-term environmental and economic costs escalate, the Chinese government has recognized the need to resolve problems caused by the vast social, environmental, and public-health impacts from the Three Gorges Dam (State Council of China 2011).

Conclusions

HKND's ESIA does not meet international standards and best-practices principles. The report was completed in an unrealistically short time and fails to fully assess the potential environmental and social impacts.

The proposed canal is one of the largest, if not the largest, civil-works projects in the world. Major risks of enormous and possibly irreversible harmful impacts are evident in the deterioration of water quality and quantity, the loss of terrestrial and aquatic biodiversity, susceptibility to natural hazards, and the displacement of indigenous people.

The overall conclusion of this review is that the canal project should be suspended while the impacts, risks, and mitigation steps are analyzed quantitatively and transparently. This megaproject should proceed only if it were unequivocally demonstrated to be economically feasible, environmentally acceptable, and socially beneficial.

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