Summary Statement of
Nicaragua Canal Environmental Impact Assessment Review Panel

On March 9th and 10th, 2015, an independent panel met for two days at Florida International University's College of Law to discuss the likely environmental impacts associated with the proposed inter-oceanic canal through Nicaragua. The goal was to review some sections of the draft Environmental and Social Impact Assessment (ESIA) conducted by the company Environmental Resources Management (ERM). Two representatives from the Hong Kong Nicaraguan Canal Development Group (HKND) were present but did not make presentations. This panel was organized by FIU's Southeastern Environmental Research Center and College of Law and focused on the ecological and hydrological assessments conducted by ERM. No sections of the Social Impact Assessment were presented or discussed. Objective analyses are urgently needed to review the final, completed report, especially the social and economic impacts of the entire project.

The panel reviewed preliminary drafts of chapters 3, 5, 6, and 7 of the ESIA, which were provided by ERM only a few days prior to the meeting. Moreover, time for discussion by the group following presentations by ERM was limited because much of the meeting consisted of presentations by ERM. Summaries of the most salient observations are presented here to convey our main conclusions.

The very short (i.e., 1.5 years) period that was approved by HKDN for this environmental study was insufficient given the magnitude of the proposed projects associated with the canal construction. Many of the impacts of construction and operation of the proposed canal will be long term and some may be irreversible. The panel of experts considered only the potential environmental impacts of the canal construction on freshwater habitats of Lake Nicaragua and the river drainages associated with the canal. Other impacts such as mitigation measures for loss of tropical forests, wildlife corridors and protection of marine habitats were very briefly considered. Because of the unprecedented magnitude of the project and the limited information available about some of the constructions plans, the effects of the proposed disturbances on the ecological processes, as well as the level and significance of many of these impacts cannot yet be fully analyzed.

The draft ESIA chapters contained baseline data and information about plans for what was presented as the most cost-effective route of the canal. However, a much more complete analysis of alternatives is essential before a scientifically robust evaluation can be completed. Further studies also need to evaluate alternative plans that impact the biota's vulnerability and essential supplies of fresh water. It appears that for a number of ESIA topics, inadequate resources were allocated to support a proper sampling effort and analysis. For example, discussions of species loss and habitat loss focused only on the construction footprint rather than the larger regional context, despite the well-documented tendency for impacts of linear infrastructure to spread well beyond the immediate footprint (Laurance et al., 2009). Given the scale of extensive habitat loss and modification likely to result from massive excavation and subsequent flooding, international standards of wildlife protection should be followed. A detailed plan and feasibility study to rescue and translocate isolated and stressed wildlife is needed that follows the IUCN guidelines to build in strong safeguards to protect wildlife welfare.

In general, data presented during the panel discussion were predominantly from very brief temporal snapshots of biodiversity as well as physical and chemical dynamics. In nearly all cases, the temporal scale of sampling was inadequate, given the state of current knowledge regarding temporal and spatial variability in natural systems.

Climate change must be considered and incorporated into every aspect of the design. Not just sea level rise, but changes in temperature, evapotranspiration, and especially rainfall. Examples of potential impacts on large lakes, reservoirs, and wetlands are well documented. Seemingly small changes in temperature and rainfall can have major impacts on water budgets (e.g., Aumen et al. 2015). Large changes in water budgets from climate change (particularly large decreases in precipitation and runoff) could dramatically affect the operation of the proposed canal.

Plans for restoration of impacted watersheds and for mitigation of numerous effects of construction and maintenance of the canal are not adequate to replace the likely loss of native species and the original habitats. The massive scale of the proposed construction activities and the complexity of land-tenure issues require much more consideration of impacts on the natural ecosystems processes related to sustaining the canal operations. Because restoration is a long and expensive undertaking, the objectives and funding for these activities need to be much more clearly defined.

Previous studies of the importance reforestation of drainage basins to avoid erosion and rapid sedimentation of reservoirs and lakes are important to consider (e.g., Heckadon-Moreno et al. 1999). A detailed plan is needed to identify strategies for improving the national capacity for watershed protection, pollution control, waste-water treatment, protection of drainage basins, and species conservation. Without this larger scope of analysis and plans for capacity building, the operational management of the project will be ineffectual. A management framework that includes sufficient funding for the national administration of the project is essential.

We present some of the main concerns from our panel discussions:

1. The canal would traverse 105 km of Lake Nicaragua, which requires removal of about 1.2 billion tons of sediment from the lake bottom for initial construction (not including long-term maintenance dredging). This dredging poses a severe threat to water quality and unique aquatic life as a result of the re-suspension of sediments containing organic matter and nutrients that induce eutrophication and hypoxia. Sediment resuspension also will occur frequently as a result of deep-draft ship traffic, and will require recurrent dredging to maintain the channel for navigation. Therefore, it is important to characterize carefully the lake sediments, including their vertical compositional profile, by coring at least down to the bottom of the planned 30 m channel, to better understand sediment transport, fate, and the potential impacts of sediment excavation and relocation in Lake Nicaragua.

The current characterization of the sediments that will be excavated for the navigation channel through the lake simply is incomplete and implausible in light of current knowledge of the geological history of the lake. The project plan states the upper 3 m of the lake sediments are comprised of fine lake sediments, whereas below that depth the lake sediments are comprised of coarser material such as sand. Because the lake is approximately 500,000 years old and is in a region of high volcanic activity, it almost certainly has more than 3 m of clay, organic rich sediments, and volcanic ash. Others cores taken from Lake Nicaragua have characterized its sediments as a diatomaceous mud mixed in with coarse volcanic material (Swain 1966, Slate et al. 2013). This type of sediment is typical for ancient lakes with long periods of deposition and volcanic activity. Additional cores should be taken in concert with paleolimnologists both to characterize the sediments and to provide samples for paleo-analyses.

There are previous studies of the geological origins of Lake Nicaragua (also known as Lago Cocibolca) and the associated lakes in this basin (e.g., Lake Managua, also known as Lago Xolotlán; Laguna de Apoyo) that report the sedimentary structure and the water chemistry of these basins. However, this information was not reviewed or included in the ERM analysis. In addition, there is no recent engineering or geological study that characterizes lake sediments to the depth required for channel dredging. This lack of information makes it impossible to estimate the amount and types of sediments to be removed by dredging and the most appropriate locations for storing dredged materials as well as their effects on water quality and food web dynamics. Moreover, maintenance dredging efforts, which will result in continued disturbance to the lake, cannot be cogently anticipated until such information has been obtained and analyzed.

Section 6.4 on Water Resources analysis considers the impacts of dredging (beginning on page 6-4-65), but this consideration seems to be limited to an evaluation of one metric – Total Suspended Solids (TSS). The draft ESIA finds that: the magnitude of the impact is considered small; the receptor sensitivity is high; therefore, the significance is moderate (which is the same finding for the residual impact). This finding of moderate significance of dredging impact simply is scientifically indefensible, because the impact analysis is based on TSS alone. Experience from other large, shallow lakes shows that sediment re-suspension can lead to large increases of dissolved nutrient and other solute concentrations in the lake water column; significant changes in the dynamics of solute exchange between the water column and the sediments; and large, and sometimes irreversible changes in the trophic status and dominant primary producers of the lake. It is recommended that the impact analysis be expanded to include these additional metrics.

The project plan indicated three dredge spoil islands will be created in Lake Nicaragua to store the fine surface sediments excavated from the upper 3 m. The remainder of the dredged material is also likely composed of fine sediments, not sand) will be disposed within the lake itself. This fine-grained clay will likely have a large impact on the in-lake sediment disposal plan and result in severe water quality impairment. Frequent dredging likely will be required to maintain sufficient depth of the navigation channel after initial construction because of re-deposition of previously dredged fine-grained, clay-rich sediments.

2. The hydrodynamic model presented to predict the circulation of currents in the lake is based on a model developed from only a few days of sampling during two years of data collection (2007, 2011). The data have not been validated and the model has not been calibrated with sufficient field information from the lake. During the proposed dredging, the planned placement of sediment underwater in rows 3 m in height along the excavated canal could change the hydrodynamics and lake circulation. The re-distribution of sediments via lake circulation (horizontal and vertical) is important to understand because it can increase nutrients leading to eutrophication and the loss of well-oxygenated waters, which could result in dead zones where no fish could live. Consequently, potential re-distribution of sediments and associated nutrients to the near-shore zone of the lake will impair water quality and lower sustainability of the fishery. These impacts will be additive to the already decreasing water quality of the lake due to rapidly increasing human impacts.

3. The lack of sufficient data on water quality across Lake Nicaragua and inflowing rivers represents a gap that greatly limits understanding of how nutrient cycling and contaminants may be affected by dredging. There were questionable (or even implausible) results presented in the lake water-quality data reported. These data apparently were not subjected to even a rudimentary level of quality control screening. For example, the concentrations presented for nitrogen constituents (e.g., ammonium) are not realistic or feasible under highly oxygenated water conditions, implying there may be issues with the laboratory analysis or modeled calculations from the biogeochemical model. Lake water quality data collected by other studies were not reviewed although these data could provide useful background information on typical water quality conditions in Lake Nicaragua. The previous studies of water quality of Lake Managua and the impacts on Lake Nicaragua during periods when the lakes are connected by high flows could be useful to consider, especially given that climate models predict more extreme variability in rainfall for this region and increased flooding resulting from more frequent hurricanes.

4. The effects of canal operation on post-construction water quality, and the trophic status of the affected rivers and Lake Nicaragua are highly uncertain but likely large in magnitude. Available data are of insufficient quantity and quality to assess current nutrient levels and trophic status of the affected surface waters. Linkages between dissolved oxygen levels in Lake Nicaragua and the ammonium, nitrate, and dissolved organic matter concentrations are particularly unclear. The data as presented do not provide an internally consistent picture. Because of the highly variable concentrations of phosphorus documented previously in Central America as a result of the geothermal sources and its potential effects on river and lake productivity (Pringle et al. 1993), a careful survey of existing conditions is needed before potential effects of the canal can be properly assessed.

5. The Lake Nicaragua biogeochemical modeling was based on only two calibration (or validation) points. One of these points was collected during a characterized dry period (April 2014), and the other during a characterized wet period (December 2013). In both cases, the correspondence between the few observed values and the modeled values was often poor. To properly calibrate an ecological-hydrodynamic model of a lake of this kind, a minimum of monthly sampling from at least twenty stations per sampling event for one year are required (Arhonditsis and Brett 2004). Multi-year data are also essential to validate predictions of the model given the importance of natural variability from droughts and tropical storms that can greatly influence inflows and outflows within the lake ecosystem.

6. Previous extreme conditions during periods of drought and hurricane-generated floods demonstrate the potential for disrupting hydrologic models that predict future water budgets based only on very short-term historic data. More attention to long-term climate forecasts is needed to provide management alternatives under climate-change scenarios. Without sufficient information about water storage capacity and means to protect the associated watersheds, there are increased risks that the canal will not function without all of the locks operating at required levels. The capacity for storing freshwater supplies to operate the canal is also unclear because the final design for the reservoirs and locks are not yet complete.

7. The water balance of the canal may be wrong. Lack of information on projected long-terms changes in regional rainfall further increase the risks of salinization over time of Lake Nicaragua, an essential source of drinking water and fisheries production as well as critical habitat for important endemic species and biodiversity in general. The report projects the canal will require an average of 60 m^3/s to operate the locks (without accounting for controlling for saltwater removal from the locks), and that this hydraulic demand will be met by the Punta Gorda River. The Punta Gorda watershed has a surface area of 8,400 km2, a mean annual precipitation of 3.2 m/year and proportional evapotranspiration of 0.68 (relative value – the ratio of runoff to precipitation). The resulting hydrology indicates an average annual runoff of 90 m^3/s. Given these estimates, the Nicaragua Canal will not have sufficient flows to operate the locks during dry years (e.g., a one-in-four year-drought) and this shortfall would be especially critical during multi-year droughts.

If the Rio Punta Gorda cannot meet the hydraulic demands for the locks, water from Lake Nicaragua would be used to operate them instead. If Lake Nicaragua were the sole source of water for the locks, there would be a 0.24 m drawdown in lake level per year (assuming Lake Nicaragua has a surface area of 8,000 km^2). This drawdown would affect the flows of the San Juan River along the Costa Rica border. If droughts in the Punta Gorda and Lake Nicaragua watersheds were to coincide, a much more dramatic decline in Lake Nicaragua water levels would occur. It is unclear if water storage in the proposed reservoir (Lake Atlanta) could meet the water demands for operating the canal. If not, it might be necessary to regulate the lake water flow to the Rio San Juan. As the only outlet of Lake Nicaragua, water restriction could have profound effects on the Rio San Juan watershed and migratory species that sustain the lake's high levels of biodiversity. Because of the great importance of the Rio San Juan, this alternative could result in severe environmental consequences that can be detrimental for the region**.**

8. Storage of water for use in operating the two sets of locks relies on construction of a large, shallow reservoir (Lake Atlanta) and a series of smaller reservoirs to control water flows during wet periods as well as generate hydropower from one reservoir. The potential for disruption of native species distributions and the likely introductions of non-native species along with a wide range of potential public health concerns (e.g., malaria, schistosomiasis) were beyond the scope of this limited review. These impacts will likely be especially important not only for managing the water budget but also for sustaining freshwater biodiversity in the species-rich Meso-American Biological Corridor, which will be disrupted by the canal and the associated reservoirs. Comparisons with the impacts of other tropical reservoirs in Panama and elsewhere would be informative.

9. Deforestation of many areas within the lake's large drainage basin has already caused significant erosion and sediment transport throughout the network of river channels entering the lake and the Caribbean coastal zone. Plans for protecting areas of concern – both within and outside of the network of formal protected areas – in these associated watersheds are not yet developed. Funding for the long-term management and protection of the watershed is undetermined. Although it is widely established that vegetative cover is essential to minimize erosion and infilling of rivers and lakes, the recent increase in deforestation is detrimental to the regional water supply and the functioning of the proposed canal. Loss of coastal mangroves and riparian forest buffers are also previously well-documented impacts throughout the tropics that need to be much more fully evaluated in this project. Plans to sustain natural forests, freshwater wetlands, and mangroves that minimize erosion, especially during storm events, are currently lacking. Protecting these habitats is also critical to retain a diverse biotic community that sustains ecosystem services such as clean water and fisheries production.

10. There are limited data on the use of the habitats for foraging and spawning as well as seasonal migration of the many species of fish within this extremely large lake. Locations and re-suspension of sedimentary dredged material could impact the migratory pathways of large bottom-dwelling fish from north to south and the quality of critical habitats in the near-shore and southern parts of the lake.

Lake Nicaragua and the associated crater lakes provide essential habitats that serve as a unique natural experiment where 13 new species of (endemic) cichlid fishes are derived from the source population from Lake Nicaragua and have evolved into several new assemblages. This source population is also economically the most important species of fish in Nicaragua will likely threatened by dredging the channel through the lake and additions of invasive, non-native species. It is essential to better understand the life history of migratory and endemic fishes and their use of near-shore habitats to evaluate future impacts to the population dynamics and to protect existing fisheries resources within the lake. Impact to the fishery of the large migratory fish could be substantial.

There are also limited data on the importance of streams to other migrating species such as decapods. Fragmenting streams with even small dams will likely disrupt migration abilities of all diadromous species. Stream sampling for all taxa, especially obligate lotic amphibian species remains extremely limited..

11. In general, terms used in the draft report to characterize species abundance should rely on existing international definitions and criteria of species rareness based on IUCN criteria and definitions. Moreover, more data needs to be collected and information provided regarding projections of population viability. Short-term observations alone are insufficient to estimate long-term impacts. Although the number of species of fishes in Lake Nicaragua is characterized by a recent synoptic survey carried out by ERM and its subcontractors, there is inadequate information on the relative and absolute abundance of the fish community to estimate viability of the populations and their typical inter-annual variability. The preliminary data by ERM and one of us (Axel Meyer) indicates that there is at least one new species of fish whose distribution is limited to the Rio Punta Gorda drainage. Furthermore, knowledge of the biodiversity and productivity of lower trophic levels is very incomplete. Although phytoplankton and zooplankton have apparently been collected, no analysis of these data was available. Sampling of benthic invertebrates in the lake is also incomplete and not yet analyzed. These organisms provide the food base for the important fisheries of the lake as well as critical components of ecosystem processes that sustain water quality. Some historic plankton data were presented, but these data were very sparse and of poor taxonomic resolution. Process rates and other functional relationships were not reported. Anecdotal evidence suggests benthic invertebrates (especially Chironomids) play a very important role and probably dominate secondary production in Lake Nicaragua. However, no field data were collected to characterize this group, nor were their rates of productivity estimated.

12. The canal would be a physical barrier that inhibits animal movement and gene flow along the Meso-American Corridor. The physical barrier would result in isolation of populations leading to inbreeding and decreased biodiversity, and it may affect 22 threatened or endangered species (including endangered emblematic species such as tapirs, spider monkeys, and jaguars), the loss of which would be irreversible. Despite this important issue, population viability analyses and the extinction risk for species that could not migrate past the canal have not been considered. It is imperative that that a detailed analysis of extinction risk is undertaken for key species that include marine and freshwater species of fishes and invertebrates and well as terrestrial plant and wildlife species.

These likely impacts are to some degree framed as part of a trade-off in which loss of habitat and associated biodiversity will be "offset" by improving the management of existing protected areas and ensuring new protected areas are established. However, no mechanism for this large land protection is proposed, nor are examples of similar projects presented. While the canal might provide a potential income stream to fund meaningful protection of remaining forested areas, there are multiple other drivers that result in ineffective protection of forested areas (such as increased accessibility to humans to currently inaccessible pristine forests and rivers), and these would need to be addressed in order to prevent further ecosystem degradation.

Reforestation is suggested as a mitigation strategy at a 1:1 ratio (e.g., 1,600 ha of forest loss in Brito to be matched by 1,600 ha of reforestation). However, the degree to which reforestation can replace lost forest is unknown, and the methods used will depend on which species and ecosystem functions can be restored. For example, if the goal is to preserve wildlife habitat, it is unknown whether the reforested habitat would ever match the original forest in terms of its suitability for native wildlife species. Given the many unknowns in tropical forest restoration, a more prudent course would be to set higher targets for habitat restoration and protection with the expectation that reforested areas will not provide the same level of habitat quality and ecosystem services overall.

13. The terrestrial biodiversity surveys presented so far provide only a brief and incomplete snapshot. However, even these cursory analyses have documented a variety of endangered and critically endangered species. The expectation that the canal would not result in regional or national extinctions of these species is not based on sufficient sampling or modeling of species' need for connectivity among different habitats. For example, the frog *Craugastor ranoides* is currently known from only one watershed in Costa Rica, and was not been reported in Nicaragua for 20-30 years. This newly described population is potentially the only known extant example in Nicaragua. Although the initial surveys were by necessity geographically limited, further investigations outside the 10-km buffer zone are necessary to conclude that canal construction will not result in extinctions by limiting connectivity of essential habitats or eliminating the habitat of unique populations.

14. In marine biodiversity assessments, information presented in the draft EISA does not adequately reflect the importance of the Pacific coast of Nicaragua for marine turtles. The Pacific coast of Nicaragua is globally important for sea turtles, with critical habitat for four of the seven species: Olive Ridley (*Lepidochelys olivacea*); Green turtle (*Chelonia mydas*) Hawksbill, (*Eretmochelys imbricata*), and Leatherback (*Dermochelys coriacea*). For the Olive Ridley, Nicaragua has two of the ten mass nesting beaches in the world, for the critically endangered Eastern Pacific Hawksbill it has >40% of all documented nesting activity, while for the Eastern Pacific Leatherback, which is in even more critical state, it is one of the few locations where the species is extant. Furthermore, surveys taken for the ESIA seem to have missed a number of important solitary nesting beaches used by green and hawksbill sea turtles – for example, at Playa Escondida, which is quite near the planned Brito port. With a rich, seasonal area of upwelling in the south, the Pacific coastal zone is also important for whales, large pelagic fish, and other marine biodiversity.

Issues of large-scale ecosystem management are critical to the Pacific coast, in addition to the smaller, site-specific impacts as presented in the baseline information on marine biodiversity. For example, the fate of La Anciana, a very small marine protected area that encompasses Brito, depends on the management of the much larger seascape of which it is part, including Chacocente and La Flor marine protected areas, located to the north and south of Brito respectively. Other key issues that should be addressed in the ESIA include: managing land-based threats such as siltation, improving baseline knowledge of currents, species and habitat distribution, turtle movement patterns and routes, and seasonal productivity patterns to better predict the potential impacts of canal construction and operation on the marine ecosystem.

Overall, much more extensive sampling is needed over several seasons to provide a sufficient analysis of population viability and community resilience. This sampling must be matched with more developed assessments of the potential impacts of canal traffic on marine biota and associated ecosystem services.

15. A thorough review of peer-reviewed literature as well as published reports of previous environmental studies should be completed and incorporated into the environmental analysis to frame the historical, current, and potential future changes to the region. Examples of the numerous sources are included below to illustrate the scope of the research review needed for a project of this magnitude.

REFERENCES

Ahlgren, I., R. Eriksson, L. Moreno, L. Pacheco, S. Montenegro-Guillén, S., and K. Vammen. 2001. Pelagic food web interactions in Lake Cocibolca, Nicaragua. Verh. Internat. Verein. Limnol. 27(4):1740-1746.

Alsina, M.A., I. Saratovsky, J.F. Gaillard, and P.A. Pastén. 2007. Arsenic speciation in solid phases of geothermal fields. Developments in Earth and Environmental Sciences *7*:417-440.

Arhonditsis, G.B., and M.T. Brett. 2004. Evaluation of the current state of mechanistic aquatic biogeochemical modeling. Where are we? Marine Ecology Progress Series 271: 13-26.

Aumen, N.G., K.E. Havens, G.R. Best, and L. Berry. 2015. Predicting ecological responses of the Florida Everglades to possible future climate scenarios: Introduction. Environmental Management 55:741–748.

Bussing, W.A. 2008. *Astyanax cocibolca*, a new characid (Pisces: Ostariophysi) from Lake Nicaragua, Central America. Revista Biologia Tropicale 56:1361

Calero, S., I. Fomsgaard, M.L. Lacayo, V. Martinez, and R. Rugama. 1993. Toxaphene and other organochlorine pesticides in fish and sediment from Lake Xolotlán, Nicaragua. International Journal of Environmental Analytical Chemistry 53:297-305.

Cisneros, R., E.I. Mangas, and M. Van Maren. 1991. Qualitative and quantitative structure, diversity and fluctuations in abundance of zooplankton in Lake Xolotlán (Managua). Hydrobiological Bulletin 25:151-156.

Cole, G.A. 1976. Limnology of the great lakes of Nicaragua. Investigations of the ichthyofauna of Nicaraguan lakes. School of Life Sciences, University of Nebraska, Lincoln. Paper 3:1-15.

Erikson, R., E. Hooker, M. Mejia, A. Zelaya, and K. Vammen. 1998. Optimal conditions for primary production in a polymictic tropical lake (Lake Xolotlán, Nicaragua). Hydrobiologia 382: 1–16.

Gutiérrez, M.A., 2001. Total mercury concentration in tilapia in fishing sites of fishing communities in lake Xolotlán. Encuentro 58: 91-102.

Guzman, H. M., R. Cipriani, and J.B.C. Jackson, J. B. C. 2008. Historical decline in coral reef growth after the Panama Canal. AMBIO: a Journal of the Human Environment 37: 342–346.

Heckadon-Moreno, S., D.R. Ibáñez and R.S. Condit. 1999. La Cuenca Del Canal: Deforestación, urbanización y contaminación. Smithsonian Tropical Research Institute. 120 pages.

Lacayo, M., 1991. Physical and chemical features of Lake Xolotlán (Managua). Hydrobiological Bulletin 25:111-116.

Lacayo, M., A. Cruz, J. Lacayo, and I. Fomsgaard. 1991. Mercury contamination in Lake Xolotlán (Managua). Hydrobiological Bulletin 25:173-176.

Lacayo, M.L., A. Cruz, S. Calero, J. Lacayo, and I. Fomsgaard. 1992. Total arsenic in water, fish, and sediments from Lake Xolotlan, Managua, Nicaragua. Bulletin of Environmental Contamination and Toxicology 49:463-470.

Laurance, W. F., M. Goosem, and S.G.W.Laurance.2009. Impacts of roads and linear clearings on tropical forests. Trends in Ecology & Evolution 24:659–669.

Montenegro-Guillén, S. 1991. Limnological perspective of Lake Xolotlán (Managua): the PLALM. Hydrobiological Bulletin 25:105-109.

Pringle, C.M., G.L. Rowe, F.J. Triska, J.F. Fernandez, and J. West. 1993. Landscape linkages between geothermal activity and solute composition and ecological response in surface waters draining the Atlantic slope of Costa Rica. Limnology and Oceanography 38: 753-774.

Rothlisberger, J. D., D.C. Finnoff, R.M. Cooke, and D.M. Lodge.2012. Ship-borne nonindigenous species diminish Great Lakes ecosystem services. *Ecosystems 15*: 462–476.

Slate, J.E., T.C. Johnson, and T.C. Moore. 2013. Impact of pre-Columbian agriculture, climate change, and tectonic activity inferred from a 5,700-year paleolimnological record from Lake Nicaragua. Journal of Paleolimnology 50:139-149.

Swain, F.M., 1966. Bottom sediments of lake Nicaragua and lake Managua, Western Nicaragua. Journal of Sedimentary Petrology 36:522-540.

Thorson, T.B. 1971. Movement of bull shark- *Carcharhinus leucas*, between Caribbean Sea and Lake Nicaragua. Copea 1971:336-338.

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

Villa, J.D. 1976. Ichthyology of the lakes of Nicaragua: Historical perspective. In: T. B. Thorson (ed.). *Investigations of the Ichthyofauna of Nicaraguan Lakes*. School of Life Sciences, University of Nebraska, Lincoln.

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