Fachhochschule Köln
Cologne University of Applied Sciences

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA

PROGRAMAS MULTIDISCIPLINARIOS DE POSGRADO EN CIENCIAS AMBIENTALES

AND

COLOGNE UNIVERSITY OF APPLIED SCIENCES

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

THE DEVIL COMES THROUGH WATER: INVASION OF THE DEVIL FISH (LORICARIIDAE) IN THE GRIJALVA RIVER, MEXICO.

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

DEGREE AWARDED BY

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

AND

MASTER OF SCIENCE

TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

IN THE SPECIALIZATION: RESOURCES MANAGEMENT

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PRESENTS:

VIRIDIANA WENDY VELÁZQUEZ VÁZQUEZ

CO-DIRECTOR OF THESIS PMPCA

JOSÉ DE JESÚS MEJÍA SAAVEDRA

CO-DIRECTOR OF THESIS ITT:

CLAUDIA RAEDIG

ASSESSOR:

CÉSAR ARTURO ILIZALITURRI HERNÁNDEZ

SAN LUIS POTOSÍ, MÉXICO JULY, 2013

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NAME OF ASSESSOR	CÉSAR ARTURO ILIZALITURRI HERNÁNDEZ

SAN LUIS POTOSÍ, MÉXICO

JULY, 2013

PROYECTO FINANCIADO POR:
PECES DIABLO (FAMILIA LORICARIIDAE): DISTRIBUCIÓN ACTUAL, POTENCIAL DE DISPERSIÓN E IMPACTOS EN LOS ECOSISTEMAS ACUÁTICOS MEXICANOS.
Numero de convenio: 108334. CONACYT

PROYECTO REALIZADO EN:

PMPCA

FACULTAD DE MEDICINA

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

CON EL APOYO DE:

DEUTSCHER AKADEMISCHER AUSTAUSCH DIENST (DAAD)

CONSEJO NACIONAL DE CIENCIA Y TECNOLOGÍA (CONACYT)

LA MAESTRÍA EN CIENCIAS AMBIENTALES RECIBE APOYO A TRAVÉS DEL PROGRAMA NACIONAL DE POSGRADOS (PNPC - CONACYT)

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Name / *Nombre*: Viridiana Wendy Velázquez Vázquez

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Esta tesis es para mi querida familia: mi Mami, mis hermanas Gaby y Les, mi bichito María Gabriela y mi pelón Juan Emiliano, mi Papi, mi abuelita, mi tía Chirita, Marichú y Eli… todos ellos quienes de una u otra forma me han apoyado en todo momento. Gracias por estar siempre conmigo y darme la confianza para volar en busca de mis sueños…

ACKNOWLEDGEMENTS

Este trabajo no es el producto de mi trabajo individual sino la confluencia del esfuerzo y cooperación de personas e instituciones que me apoyaron para su realización. Van mis más sinceros agradecimientos para:

Los que se encuentran detrás del programa de maestría ENREM, por brindarme la oportunidad de ser parte de esta gran experiencia y contribuir a mi desarrollo no sólo profesional sino personal.

DAAD y Conacyt por el apoyo económico.

El Dr. Jesús Mejía por aceptarme como tesista, darme la libertad de adaptar el proyecto a la zona de estudio de mi interés y apoyarme durante la primera fase de trabajo de campo. Gracias por la confianza en mi trabajo.

La Dra. Claudia Raedig, quien más que co-directora fue una mentora, porque aparte de compartirme sus conocimientos académicos se encargó de transmitirme en cada reunión su pasión por la investigación y la ciencia. Por motivarme siempre a buscar más para enriquecer el trabajo. Por colocar mi tesis como una prioridad en sus actividades aún fuera del horario laboral.

El Dr. César Ilizaliturri, por asesorarme en la modelación y orientarme para obtener mejores resultados.

A todos los que fueron mis profesores, tanto del ITT como del PMPCA, tengan por seguro que me llevo algo de ustedes.

Marisela, Farah, Laura, Lorena y Maru, quienes, con la mejor actitud, me asesoraron con los trámites administrativos en el PMPCA.

Sandra Avendaño, aparte de ser excelente coordinadora del programa ENREM en el ITT fue una gran consejera para una estancia amena en Alemania.

A todos mis compañeros ENREM por la convivencia durante este tiempo.

Mi familia ENREM: Carlos Maticas, Duglaj Pino, Lisa Popisa, Riveritos, Andrea “Terrible” Terán y Uva Lady T con Enremsit. De corazón muchachieren gracias por todo: viajes, pláticas, aventuras, carcajadas, purificaciones, tonteras, crisis, malos momentos… una lista interminable que demuestra en realidad que nunca estuve sola. Ya los extraño!!! Paiting! Porque lo que es de ser… es de ser!!!

Ali y su hermosa familia, por su inmensa generosidad, amistad y confianza incondicional brindada. Por haberme compartido su espacio, el cual fue idóneo para culminar esta etapa.

La Sra. Juanina y el Sr. Agustín, quienes se preocuparon por darme una alimentación saludable.

Quienes estuvieron sin estar: Arely, Eme, Jhoan, Juan, Lalo, Luz, gracias por tener el comentario perfecto en el momento preciso.

Mis grandes apoyos en trabajo de campo:

- Mi mami, mujer valiente que me apoyó en la toma de fotografías con los peces.
- Mi papi, hombre ingenioso y lleno de energía que se encargó de que todo saliera bien durante la segunda etapa de campo… más de 2000 km recorridos, midiendo y entrevistando en menos de una semana.
- Don “Chuy”, maestro del volante durante la primera etapa de campo.
- Hugo, por su ayuda con las mediciones en la primera fase de campo.
- Don Luna, quien sin conocerme ni ser pescador me ayudó desinteresadamente en la captura de peces.
- Dr. Lennin Arias de la UJAT por su apoyo en el préstamo de equipo.
- Rocío López por su disposición en el préstamo de equipo.
- Las cooperativas de pescadores “Estrecho de la Herradura” “Pantanos de Centla” y “Nandambua” por la información proporcionada.
- Los pescadores por aportar su conocimiento y experiencias con el pez diablo.

The devil comes through water: invasion of the Devil Fish (Loricariidae) in the Grijalva River, Mexico.

LIST OF FIGURES

LIST OF TABLES

APPENDICES

The devil comes through water: invasion of the Devil Fish (Loricariidae) in the Grijalva River, Mexico.

ABSTRACT

Since 1995 the Devil Fish (common name for Loricariids) has been reported as invasive species in Mexico. The impacts of its presence in rivers and reservoirs include not only economic losses and fishermen unemployment due to out-competing local fish species, but also ecological consequences e.g. river shoreline erosion, degradation of water quality and depletion of endemic species. The Grijalva River belongs to an ecological zone with high biological and cultural diversity in Mexico, where until now the number of directly affected fishermen amounts to more than 12,000. In order to provide information for Loricariids management and nonnative invasion prevention, this work is based on estimating the geographical distribution of Loricariids fish family in two steps: in the first phase, a geo-referenced dataset with occurrences of Loricariids along the Grijalva River was created, climatic data is gathered and physicochemical parameters of the water in the river are measured in the field with a multiparametric probe. Some stations are sampled twice to assure the occurrence and to get an idea of the dispersal potential of Loricariids through the time. The second phase consists of creating a modeled geographic distribution range of Loricariids using statistical analysis packages (MaxEnt, Hyperniche). According to Maxent models, the variables that most contribute to the relative suitability according to the ecological niche of the Loricariids are normalized differential vegetation index (NDVI), altitude, isothermality, flow accumulation and precipitation of the coldest quarter. Additionally, using the physicochemical parameters of the water, the preferred ranges for Loricariids for water temperature, dissolved oxygen, total dissolved solids, pH and conductivity were obtained with Maxent and Hyperniche. The statistical relationships between occurrence data and predictors allow for the identification not only of areas where Devil fish is already present, but also of locations with high risk of Loricariids establishment, like the upper part of Grijalva River. The results provide a basis to design a strategic prevention plan for Loricariids invasion in the upper part of the Grijalva River.

Keywords: Devil Fish (Loricariidae), distribution model, invasive species, MaxEnt, Hyperniche, predictors, Grijalva river.

RESUMEN

Desde 1995 el Pez Diablo (nombre común para los Loricáridos) ha sido reportado como especie invasora en México. Los impactos de su presencia en ríos y cuerpos de agua incluyen no sólo pérdidas económicas y desempleo de pescadores debido a la sustitución de pesca comercial por Loricáridos, sino también consecuencias ecológicas como erosión en la rivera de los ríos, degradación de la calidad de agua y disminución de especies endémicas. El río Grijalva pertenece a una zona ecológica con gran diversidad biológica y cultural. Hasta el momento el número de pescadores directamente afectados por la presencia de Loricáridos es de más de 12,000. Con la finalidad de proveer información para el manejo y prevención de invasión por Loricáridos, este trabajo está basado en estimar la distribución geográfica de esta familia de peces en dos etapas: la primera fase consistió en crear un inventario geo-referenciado con ocurrencias de Loricáridos a lo largo del río Grijalva, obtener condiciones climáticas y medir parámetros fisicoquímicos del agua directamente en el río utilizando una sonda multiparamétrica. Algunas localidades se visitaron dos veces para corroborar la ocurrencia de los peces y obtener un estimado del potencial de dispersión de los mismos. En la segunda fase se crearon modelos de distribución geográfica de Loricáridos utilizando los programas para modelación de nicho ecológico Maxent e Hyperniche. De acuerdo a los modelos obtenidos con Maxent, las variables que más contribuyen a determinar el nicho ecológico de los Loricáridos son el indíce normalizado diferencial de vegetación (NDVI), la altitud, isotermalidad, acumulación de flujo y precipitación del trimestre más frío. Adicionalmente, utilizando los parámetros fisicoquímicos del agua, se estimaron los rangos preferidos por los Loricáridos con respecto a temperatura del agua, oxígeno disuelto, sólidos disueltos totales, pH y conductividad, estos resultados basados en las curvas de respuesta obtenidas por Maxent e Hyperniche. La relación encontrada entre datos de ocurrencia y predictores permitió la identificación no sólo de áreas donde el Pez Diablo está presente, sino también de localidades con alto riesgo de establecimiento de Loricáridos, como la parte alta del río Grijalva y la presa de Malpaso. Los resultados proporcionan una base para diseñar un plan de estratégico de prevención y manejo de la especie en la zona de estudio.

Palabras clave: Pez Diablo (Loricariidae), modelo de distribución, especie invasora, MaxEnt, Hyperniche, predictores, río Grijalva.

1 INTRODUCTION

1.1 General Background

In biogeography it is important to understand how organisms are distributed on earth, the main problem faced is the absence of complete inventories of the places where species occur, an alternative adopted was the implementation of predictive species distribution models (Tognelli *et al*., 2009). Before the utilization of species distribution models (SDM), the distribution ranges of species were determined only at small scales and the distribution was normally based on geographical barriers such as mountains or rivers (Moratelli *et al*., 2011). Some applications of the species distribution modeling are in biogeographic and conservation areas (Chefaoui and Lobo, 2008; Hirzel *et al*., 2001), to determine priority natural areas for protection (Cuervo-Robayo and Monroy-Vilchis, 2012) and to determine the dispersal potential of invasive species (Mandle *et al*., 2010; Rödder *et al*., 2009).

According to the International Union for Conservation of Nature (IUCN, 2011) invasive species are "animals, plants or other organisms introduced into places out of their natural range of distribution, where they become established and disperse, generating a negative impact on the local ecosystem and species". After habitat destruction, they are the second most significant cause of species extinction around the world. Invasive species can compete with native species, become pests and cause ecological, economic and health impacts (IUCN, 2011). Recognizing that, the National Commission for the Knowledge and use for biodiversity (CONABIO) in Mexico has preliminarily identified, a total of 800 invasive species of high impact to biodiversity which 665 correspond to plants, 77 to fish species , 10 to amphibian and reptiles, 30 birds and 6 mammals (Conabio *et al*., 2007). This research is focused on the most common fish species of the Loricariidae fish family, also known as "Plecos" or "devil fish" (*H. Plecostomus*, *P. pardalis* and hybrids).

Loricariids are considered in the priority list of species at a National level that are impacting freshwater habitats at an ecosystem level (Conabio *et al*., 2007). According to that, devil fish invasion requires immediate action as mentioned in the National Strategy for Invasive Species in Mexico, emphasizing on its prevention, control and eradication (Comité Asesor Nacional sobre Especies Invasoras, 2010).

Therefore to contribute to this National Strategy, it is important to predict places where the species is present and identify the areas that have the possibility to be invaded, which can be achieved using species distribution modeling (Mandle *et al*., 2010).

1.2 Problem Statement and Justification

Previous studies have reported that Loricariids have a great capacity of geographic dispersion due to their physiological and adaptive characteristics that have led them to become a plague (Capps *et al*., 2011; Krishnakumar *et al*., 2009). In Mexico its presence and dispersal has been reported since 1995 in Michoacán where they caused production's decrease of commercial fish of up to 70%. (Mendoza *et al*., 2007) and ecological impacts such as water quality problems, modification of the trophic structure of the ecosystem and competition (Mendoza Alfaro *et al*., 2009a). Since the year 2000 Loricariids have been found in some rivers of Chiapas and Tabasco (Mendoza Alfaro *et al*., 2009b); some reports have documented the fishermen's concern due to the decrease in the amount of commercial fish species. An alternative to attend this situation is to obtain information for prioritizing invasive species management by identifying the potential habitat, this can be done by species distribution modeling (SDM) (Poulos *et al*., 2012) which is the main focus of this research.

1.3 Objectives

1.3.1 General

Determine the actual and potential distribution of fish species of the Loricariidae family and identify socio-economic impacts in the Grijalva river basin, Mexico.

1.3.2 Specifics

- ❖ Elaborate a geo-referenced inventory of presence/absence of Loricariids in the Grijalva River watershed.
- ❖ Identify environmental and physicochemical predictors that define the ecological niche of the Loricariids.
- ❖ Model the potential distribution of the Loricariids using maximum entropy models.

- Obtain response curves of physicochemical variables using a nonparametric model (Hyperniche)
- Represent the distribution model of Loricariids that best fits using thematic cartography.
- Identify socio-economic impacts of Loricariids in the study area.
- Generate an outline to provide information for a preventive plan in areas of potential risk and a Loricariids management for locations where it is already present.

2 ARMOURED CATFISHES

2.1 Origin, adaptive characteristics

Armoured catfishes belong to two families of fish which originated in South America, the Callichthyidae and the Loricariidae. Those belonging to the first family are characterized by two rows of invertebrate plates on each side of the body, can breathe air and thanks to that are tolerant to water with low oxygen content (Mendoza Alfaro *et al*., 2009b). This work is focused on the Loricariidae family, which is the largest family of catfish species, according to Armbruster (2004) it comprises 83 valid genera up to January 2006, as well as 825 nominal species, of which 709 are considered valid. In the last ten years 195 species where added, up to date the family comprises 864 valid species and around 135 available but still undescribed (Eschmeyer and Fong).

A distinctive feature of Loricariids is a bone plate as if it were armor along three lines through its dorsal surface, its ventral body is flat, all species possess a mouth developed to "suck" organic matter and algae from the substrate, as well as to adhere to different surfaces and remain there in spite of the water flowing in their natural habitat (Mendoza Alfaro *et al*., 2009b).

Loricariids have experienced adaptive radiation, which means an increase in taxonomic diversity due to the spread and adaptation to different environments, they have colonized almost all freshwater habitats, from Costa Rica to Argentina including torrential waters in the Andes, quiet waters of the estuaries, acidic waters of the Guiana Shield and subterranean systems. (Covain and Fisch-Muller, 2007)

2.2 Studies on the invasion of Loricariids in the world: some impacts

Armored catfish are endemic to South and Central America (Cramer *et al*., 2011). They constitute one of the greatest threats to the biodiversity of continental aquatic ecosystems and fisheries of freshwater in Mexico because there are at least one dozen species in the wild beyond its area of distribution (exotic) and they have become invasive species in various regions of the planet such United States (Pound *et al*., 2010), Mexico, Taiwan, Philippines, Japan and Singapore. (Mendoza *et al*., 2007)

The success of their wide geographic distribution is due to physiological and metabolic characteristics that have helped them adapt to a wide variety of habitats, these adaptations include their optional ability to breathe air in response to aquatic hypoxia using their stomach as an accessory organ for breathing (Graham and Baird, 1982). Their armor have protected them against predators, especially birds such as pelicans, which have been injured or killed while trying to fish them (Bunkley-Williams *et al*., 1994). Their diet is mainly detritivourus; in one study amorphous detritus and picoplankton were found in 100% of the guts of *H. Loricariids*, followed by diatoms, and algae (Pound *et al*., 2010). In other research Chaichana and collaborators (2011) have found in the gastrointestinal tract of the adult fish a greater proportion of grit, accompanied by detritus and benthic animals. The species *P. pardalis* can tolerate deteriorated and eutrophic environments with low water quality, typically cloudy, low levels of dissolved oxygen and lots of organic matter and nutrients. The establishment of *Pterygoplichthys* seems to have negative effects on the native species of the Nong Yoi Canal in Thailand, as was found downstream that *Pterygoplichthys* represented 100% of species composition. (Chaichana *et al*., 2011).

P. multiradiatus, also belonging to the family Loricariidae is a popular pet around the world and is known as "algae eater", has been found in the Chackai channel in Kerala, India and it is believed that it was introduced as a result of the Treaty for marketing of ornamental fish. They are known to have negative impacts on the periphyton and due to their feeding habits alter trophic chain decreasing the amount of food for several aquatic insects. Another impact reported is that it has replaced herbivorous fish and has caused economic loss to fishermen for damage to fishing gears, especially cast and gill nets. (Krishnakumar *et al*., 2009)

The *Loricariids* nest in colonies, this causes an important sediment removal because they come to dig up to 1.5 meters (Figure 1), which contributes to the soil erosion of riverbanks causing instability (Aguirre Muñoz *et al*., 2009; Nico *et al*., 2009) and affecting the water quality (turbidity is increased).

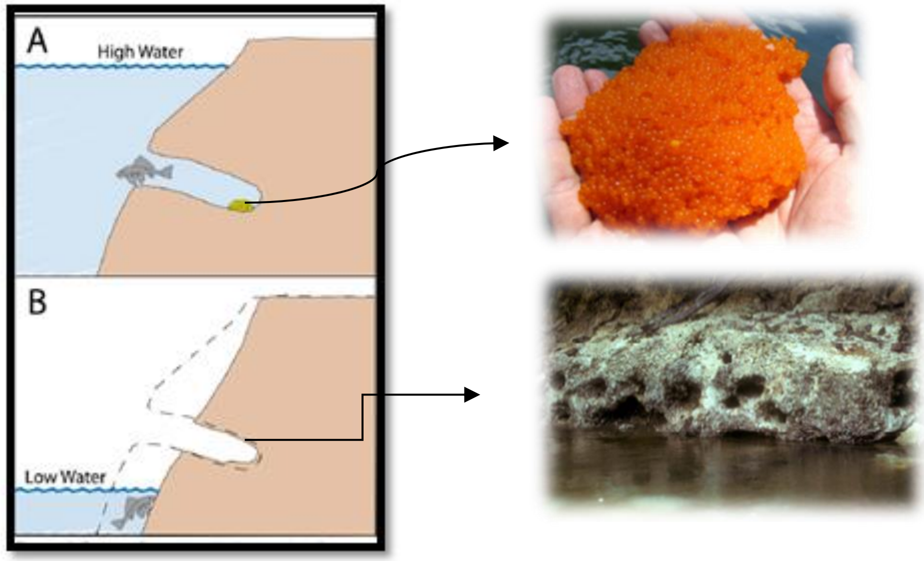

Figure 1. Profile and longitudinal section of a nest of *Loricariids*. Possible consequence of erosion. (A) Active nest, water covers the river bank, photo of eggs; (B) Inactive nest, when the water level decreases. Dotted line is the river bank profile prior to erosion. Photo: river bank eroded by several nests. Source (Nico *et al*., 2009)

As the turbidity of water increases, the penetration of sunlight to the bottom of the river or lake is reduced, hampering photosynthesis of green algae and altering biogeochemical cycles (e.g. that of nitrogen); this could also modify the patterns of normal spatial distribution of nutrients, algae and detritus causing habitat alteration (Matthews, 1998), losses due to carbon sequestration disruption and reduction in the quality of water (Stabridis Arana *et al*., 2009).

Although it has not been demonstrated, it is probable that the Loricariids can act as carriers and transmitters of parasites and pollutants (IUCN, 2011).

2.3 Presence of Loricariids in Mexico

Loricariids have a broad geographical distribution, their presence in Mexico dates back at least to the year 1995 when it was first reported in the Mezcala River, which belongs to Balsas river watershed; subsequently in June 1997 Loricariids were seen in the Adolfo López Mateos reservoir, better known as Infiernillo, where losses have been calculated to reach an amount of US$16.5 million annually considering fishing activities, natural capital and the aquarium trade (Stabridis Arana *et al*., 2009). Loricariids introduction also had a social significant cost, due to the *Loricariids* replacement (no less than three species and probable hybrids) of the tilapia capture by 70 percent. This situation led to 3,600 unemployed fishermen and affected indirectly 46,000 people. In 2001 some specimens were captured in Tecpactán river, Chiapas which belongs to the Grijalva river watershed (Aguirre Muñoz *et al*., 2009)

In the state of Tabasco seven suckermouth armored catfish species were captured for the first time in 2005 in the vicinity of Frontera, Tabasco; the fish species were identified as *P. pardalis*, better known as Amazon sailfin catfish or plecostoma leopardo, as they had external bony plates forming a flexible armor the predators did not had experience with this species and had less predation pressure than in its native range. Due to that it is assumed that habitat adaptations might play an important role in determining the distribution of the species after having adapted to the Grijalva-Usumacinta river basin (Wakida-Kusunoki *et al*., 2007). Due to this report, in 2007, a workshop was held in the municipalities of Balancán and Tenosique (Grijalva-Usumacinta hydrological complex), in which it was concluded that the presence of the Loricariids has had negative impacts in the area due to its distribution in a variety of environments like rivers, lagoons or soft and rocky shallows. The number of directly affected fishermen is 12,887 and the indirectly affected people are 51,548 (Barba Macías and Estrada Loreto, 2007)

Another study was carried out in Tabasco, aimed at determining the salinity tolerance of the Loricariids in the Grijalva-Usumacinta delta, this measure is an important physiological attribute that could determine the success of the invasion and the pattern of distribution of introduced aquatic organisms. In this work Capps *et al*., (2011) shows quantitative evidence that the *Pterygoplichthys pardalis* are physiologically able to survive in mesohaline conditions for long periods and also suggests that the ones that are currently present in Mexico as non-native populations are invading and presumably exploiting estuarine and coastal environments, probably as feeding area and potential dispersal routes (Capps *et al*., 2011). Since the recent sightings while starting the Master Thesis research had been in this basin and due to its ecological and cultural importance, the study area of this work will be the Grijalva River watershed.

3 STUDY AREA

3.1 Location

Mexico is divided into 37 hydrological regions (CONAGUA, 2007). Two of them are considered in this work. Being Grijalva-Usumacinta the most important because Grijalva River is located within it. Coatzacoalcos region was considered due to the closeness to the Grijalva River. Grijalva-Usumacinta region comprises eight sub-basins while Coatzacoalcos region one. The Grijalva River, located in Southeast Mexico (Figure 2). The Grijalva is a cross-border watershed originated in Los Cuchumatanes sierra in Guatemala and crosses the states of Chiapas and Tabasco. It is part of the Grijalva-Usumacinta hydrological complex, which is one ecological zone with high biological and cultural diversity in the Mexican territory. It represents only 4.7% of the landmass of the country but their ecosystems contain 64% of known national biodiversity. Its importance lies in the ecosystem services provided such as biogeochemical regulation cycles, hydrological flow, recharge of aquifers and biodiversity maintenance; as well as ecological functions such as climate regulation, resilience to external shocks, erosion and sediment control, among others (Instituto Nacional de Ecología, 2007).

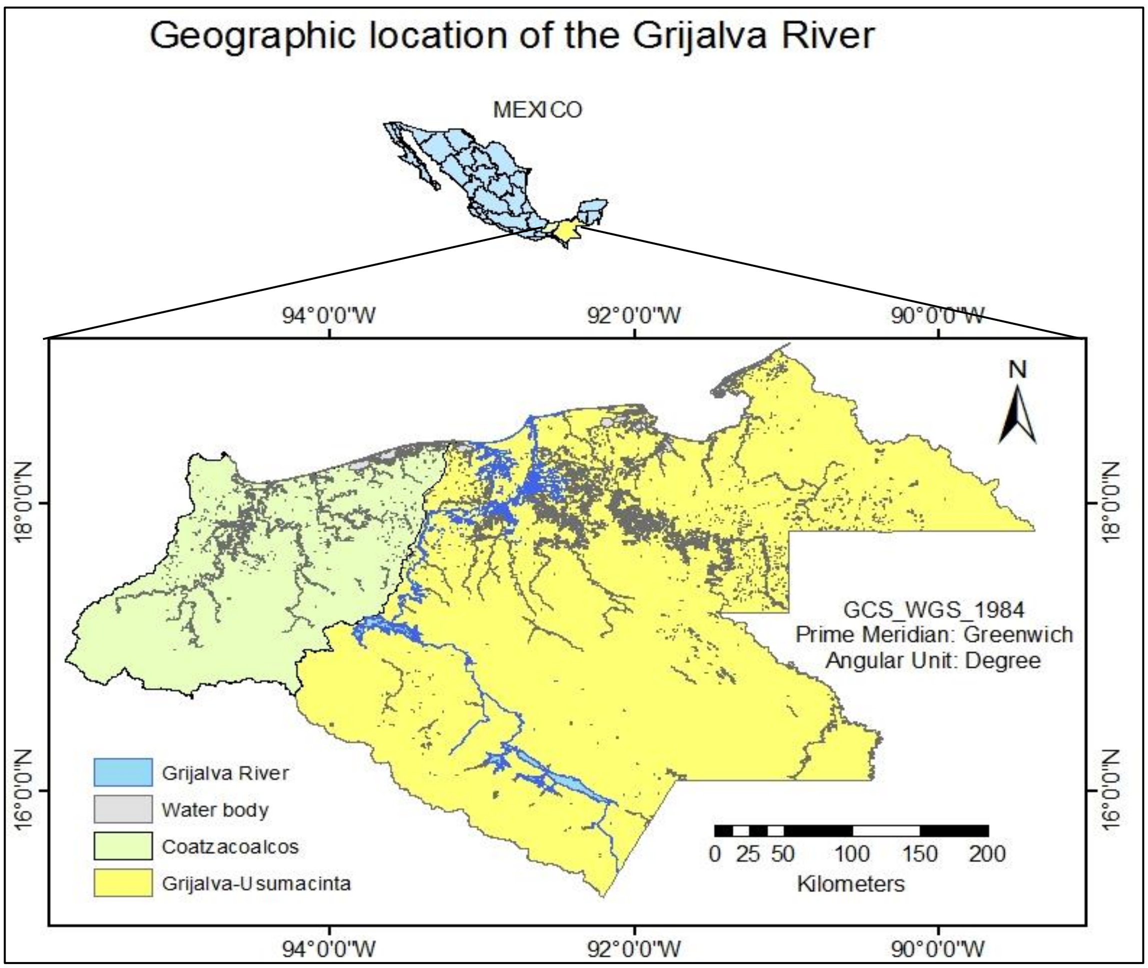

Figure 2. Geographic location of the Grijalva River. Hydrology of the study area comprising two hydrological regions (Coatzacoalcos and Grijalva-Usumacinta). Based on shapefile retrieved of (INEGI, 2010)

3.2 Ecological Importance

Along the Grijalva River are located two important natural protected areas:

- Pantanos de Centla was declared as a biosphere reserve in 1992, with a surface of 302,706 ha, it is located northeast of the State of Tabasco. It is integrated by three basins: the Usumacinta, Laguna de Términos and the Grijalva River. The Grijalva-Usumacinta Delta is considered the most important system of North and Central America and occupies the seventh place worldwide by the discharge volume, the extension of its marshes and wetlands and the biological richness concentrating almost 12% of the aquatic and sub-aquatic vegetation of Mexico (ParksWatch, 2004). In 1995 Pantanos de Centla was registered in the RAMSAR Convention on Wetlands of international importance (The Ramsar Convention on Wetlands, 2013)
- Sumidero Canyon (Cañón del Sumidero), declared National Park in 1980 has a surface of 21,789 ha. It is made up of three hydrological systems: the Grijalva river, the Chicoasen dam and the karstic hydrological system of the lime plateaus adjoining with the canyon. The Cañón del Sumidero National Park presents geological features, unique in its kind, with cliffs of limestone and basalt rocks up to 1000 meters high, formed by the passage of the Grijalva River. In its interior there are fragile terrestrial and aquatic ecosystems, which are the habitat and one of the last refuges of animal species in eminent danger of extinction, such as the Hoco pheasant (*Crax rubra*), spider monkey (*Ateles geoffroyi*) and the river crocodile (*Crocodylus acutus*), as well as endangered species such as the ocelot (*leopards wiedii*). The national park has also the International recognition of the RAMSAR Convention on Wetlands. (del Castillo, 2003).

Table 1 shows the total surface that has each of the major rivers of the Grijalva-Usumacinta watershed. It can be seen that the Usumacinta River is the most extensive; however, it covers a smaller territory in terms of its location (most of the river is located in Guatemala).

Table 1. Surfaces in square kilometers of the Grijalva-Usumacinta watershed and corresponding area to each country obtained from Rubio Gutiérrez and Triana Ramírez (2006)

River / Country	Mexico (Km^2)	Guatemala (Km^2)	Total per rivers (Km^2)	Average anual runoff (Mm^3)
Grijalva	52,348.08	5,610.00	57,958.08	36,493.88
Usumacinta	30,627.98	44,373.81	75,001.79	62,206.623
Total per country	82,976.05	49,983.81	132,959.87	98,700.506

3.3 Topography

An important aspect considered in choosing the Grijalva River watershed, is that the weather conditions vary dramatically as the Grijalva moves downstream, the high and middle Grijalva have a precipitation average ranging between 1200 and 1700 mm annually, since this area is located between two weather barriers: the mountainous areas of the North and coast of Chiapas. In the upper part of the basin of the lower Grijalva (to the South) is located one of the areas of greater precipitation in Mexico, with more than 4000 mm per year. In the plains of the lower Grijalva precipitation ranges between 1700 and 2300 mm, the influence of atmospheric systems is similar to that in the upper part of the lower Grijalva, but precipitation decreases because there are no contributions by the orographic rise. Another feature taken into account was the altitudinal gradient along the basin of the Grijalva River (Figure 3), the part of the upper Grijalva is 2,100 meters above sea level, reaching the Gulf coastal plain at sea level (Rubio & Triana, 2006).

Grijalva River contributions are regulated through four dams (Figure 3). “La Angostura” dam is located in the Upper Grijalva River. Grijalva downstream borders the city of Tuxtla Gutierrez, Chiapas State capital and downstream is located the dam “Chicoasén” in the region of the National Park “Cañón del Sumidero”. Malpaso and Peñitas are the last two dams located along the Grijalva river in downstream direction (Rubio & Triana, 2006).

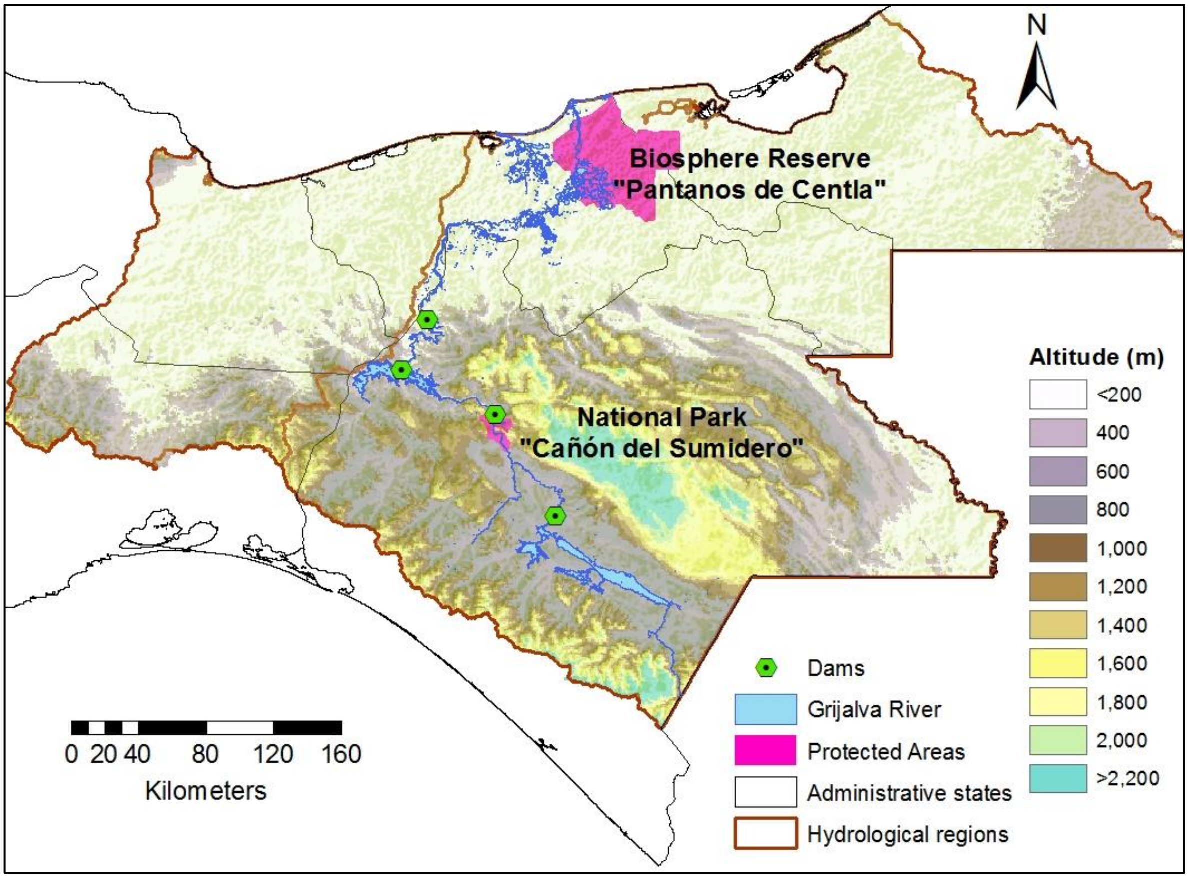

Figure 3. Orographic profile of the Grijalva river basin. Location of dams and protected areas. Based on Digital Elevation Model retrieved of (CGIAR-CSI, 2004)

4 THEORETIC FRAMEWORK

4.1 Niche concepts

What is a niche? Peterson (2011) defines the fundamental niche of a species, according to Hutchinsons's (1957): as an n-dimensional hypervolume of environmental variables or "the set, in a multidimensional space, of environmental states within which a species is able to survive" (Peterson *et al*., 2011).

Hutchinson (1957) realized that competition reduces the fundamental niche of a species translated into the area that it could occupy, this reduced area of the fundamental niche was called realized niche (Soberón, 2007).

Since then, the variables considered in the niche where classified into two groups: the *scenopoetic*, meaning the ones that are not consumed and for which no competition occurs, and the *bionomic* variables which describe environmental aspects that are impacted by the species by consumption or other modifications (Peterson *et* *al*., 2011). According to the group of variables, the niche can be separated into two main classes: the Grinnelian class based on fundamentally non-interactive variables (scenopoetic) and environmental conditions that describe the niche of a species at a broad geographical scale; the other class is the Eltonian class focused on biotic interactions and resource-consumer dynamics (bionomic variables) which is applied at local scale (Soberón, 2007). Although both classes of niches are important to understand the distribution of individuals of a species, the Grinnellian class is the most used because it is suited to low spatial resolution (maximum 1 km^2), whereas the Eltonnian class require high spatial resolution characteristics (between 10^{-3} - 10^0 km^2). Therefore Eltonnian class is rarely used because it requires creating the predictor layers for every research project (Soberón, 2007) . Soberón (2007) defined areas of distribution as “sets of grid cells in geographic space, defined by actual or potential ways in which presences of individuals of a species can be detected”.

There are four classes of factors that determine the presences of a species in a specific area (Soberon and Peterson, 2005):

1. Abiotic conditions, includes aspects of climate, physical environment, etc. responsible for imposing physiological limits on species’.
2. Biotic factors: set of interactions with other species, modify the ability to maintain populations and can be positive like mutualism or negative like competitors.
3. Regions accessible to dispersal. Important to distinguish species’ actual distribution from its potential distribution.
4. Capacity to adapt to new conditions.

The dynamic interaction of these factors in different proportion at different scales produces a complex and fluid concept called *geographic distribution of a species*.

It is assumed that a species will be present at a specific location where three situations converge (Figure 4) favorable abiotic conditions in a region (A) that maintain the growth rate positive; an appropriate suite of species (hosts, pollinators) and biotic interactions (diseases, specialized predators) represented in region (B) that allows a total positive growth rate and a geographic region(s) (M) that are accessible to the dispersal capacities of the species (Soberon and Peterson, 2005).

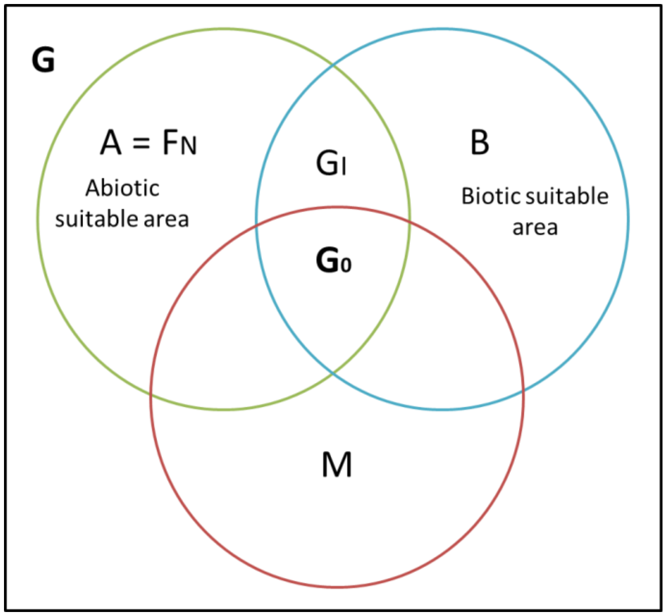

Figure 4. BAM Diagram that represents the factors affecting the distribution of a species. The Geographical space is represented by G. The green area A is the abiotic suitable area, the blue circle B represents the right combination of interacting species to occur. A ∩ B = GI mean the geographic area of the Realized Niche (RN) of the species. The circle M in red comprises the regions that are accessible to the species; there are no barriers that limit colonization or movement. A ∩ B ∩ M = Go is the area equivalent to the geographic distribution of the species. Adapted from (Peterson *et al.*, 2011; Soberon and Peterson, 2005; Soberón, 2007)

4.2 Factors influencing species distribution

Three kind of gradient factors were proposed by Austin (1980):

1) Indirect are the ones that do not have physiological effect on the species growth or competition, like the altitude, latitude and longitude. And the relation between species distribution is based on a location-dependence correlation with other variables like temperature and precipitation.
2) Direct factors have a physiological effect but are not consumed, like pH and temperature.
3) Resource gradients are those variables consumed by species like water and nutrients.

Environmental predictors that affect species distribution have been identified by Austin (2002) to be either proximal (causal) or distal (proxy or surrogate) according to its position in the chain of processes that link the predictor to the species. The most proximal variables are the cause of the species response, in the case of plants; the availability of nutrients in the root part is more proximal than the quantity of total nutrients in the soil. The Indirect factors or gradients are distal variables. Although the models based on proximal resources and direct gradients lead to more robust predictions, they are more difficult to achieve in terms of knowing what to measure, resources and time. To generate GIS coverage for these variables at different scales is complicated. (Austin, 2002)

4.3 Species Distribution Modeling

Austin (2002) identified the ecological model, data model and statistical model as the three main components for statistical modeling in ecology for plants. This is a general approach and will be applied in this work to the distribution modeling of Loricariids. The first component is the theory behind the ecology related to the species (the more knowledge, the more robust prediction) in this case is related to the knowledge of the requirements that the species prefer to inhabit; the data model comprises all the information needed for modeling, how is it collected and how it will be measured, adapted to this work is to collect the values of the predictor variables either by direct sampling or consulting literature. The statistical model refers to the choice of the statistical method to be used and how is it validated. Actually different methods to model species distribution are available, the most applied are generalized linear models (GLM), generalized additive models (GAM), vector GLM and GAM (VGLM/ VGAM), multiple additive regression splines (MARS) generalized linear and additive mixed models (GLMM/GAMM), artificial neural networks (ANN), boosted regression trees (BRT), bayesian approach (BA), genetic algorithm (GA) and classification and regression trees (Elith *et al*., 2010; Guisan *et al*., 2006; Thuiller and Munkemuller, 2010). Most of these response models are additive, which could result in a simplistic form of the response curves that do not fit to the theoretically accepted response of species to environmental variables (McCune, 2004). There is no rule that define species response shapes to predictors because it would depend on the nature of the variables; for example, if the modeling is done with indirect variables any shape of the response curve could be expected making more difficult to decide the type of parametric model to be used (Austin, 2002). An alternative to avoid making assumptions about the shape of response curves of species to different factors is to use non parametric multiplicative regression models (McCune, 2004).

The models are designed to accept as occurrence input presence/absence data, the choice of the method also implies the data available, which typically is a list of geo-referenced list of localities were species has been observed (Phillips *et al*., 2004)

5 METHODS AND MATERIALS

5.1 Geo-referenced inventory

A geo-referenced inventory consisting on 66 ocurrences of Loricariids was created from two different sources of information (Appendix 1) as described as follow.

5.1.1 *Primary occurrence data*

5.1.1.1 Potential distribution

A route was designed to sample the Grijalva River in two different periods and different sections. The first field work phase, carried out at the end of the month of July 2012 started in the lowest part of the Angostura dam located in the State of Chiapas up to the delta of the Grijalva-Usumacinta hydrological complex, in the State of Tabasco. During this phase 29 sampling points were geo-referenced with a Garmin® GPS (GPSmap62s) in UTM Coordinates system in a World Geodetic System 84 (WGS 84). It was documented *in situ* the presence or absence of Loricariids. The presence of Loricariids was determined either by direct observation of the species in the river or with fishermen (Figure 5), species carcasses or nests in the area or by fishermen identification while seeing photographs during an interview.

Figure 5. Loricariid hold by a fisherman in one of the locations sampled.

Absence of Loricariids was appointed by absence of nests in the river banks, no direct observation or Loricariids in the river, no carcasses found and no identification of Loricariids by fishermen. In addition, six physicochemical parameters (pH, Temperature, Dissolved Oxygen (DO), Conductivity, Oxidation-Reduction Potential (ORP) and Total Dissolved Solids (TDS)) and one topographic (Altitude) were measured in every sampling point in the river using multiparametic probes (HACH HQ40d and HANNA HI9828) see Figure 6.

A) B) C)

Figure 6. A) Sampling physicochemical parameters of the rivers´water. B) Sensors of the multiparametric probe. C) GPS

The second phase of the field work, held in March 2013, included the highest part of the Grijalva River, from the Angostura dam (~500 meters altitude) to the frontier with Guatemala (altitude > 1000 meters). Trying to find the limits of the Loricariids geographic distribution, sample points were established in three different directions: to the west, in Calzadas River, which is an affluent of the Coatzacoalcos river basin; to the east in Atasta, Campeche and to the southeast in Salto de Agua, Chiapas the last two belonging to the Grijalva-Usumacinta hydrologic complex. The same procedure was implemented just with the difference that only one multiparametric probe was used (HACH HQ40d), excluding ORP and TDS measures on this points. The number of sample points measured was nine.

In addition, eleven occurrence data were geo-referenced by the research group in the surroundings of the study area (Campeche, Veracruz and Tabasco).

The total number of sample points measured directly is 49, 34 with Loricariids occurrences and 15 without (Figure 7).

5.1.2 Ocurrence data from literature

5.1.2.1 Native distribution

Occurrences of the Loricariids were obtained from the Global Biodiversity Information Facility database (GBIF, 2012). The search was made with "Loricariidae" as keyword and all the available networks were selected. The result was downloaded as an Excel comma separated value format (.csv) and classified by country in order to use only the native occurrences (from Central and South America) and not invaded ranges (Indonesia, Taiwan, Germany, United States, Myanmar, Mexico, etc.). The result with only native presence points comprised more than 7,000 occurrences belonging to 95 different genus of Loricariidae fish family. The final set of occurrences used was selected based on Loricariids genus that have already being found and identified in the study area, these are Hypostomus and Pterygoplichtys (Capps *et al*., 2011; GBIF, 2012; Mendoza Alfaro *et al*., 2009a; Wakida-Kusunoki *et al*., 2007), this categorization reduced the data occurrences to 211 (Appendix 2). This set of occurrences is named NATIVE OCCURRENCES.

5.1.2.2 *Potential distribution*

A total of 17 presence points of Loricariids were obtained from different literature sources: research articles or newspaper news. When the report did not specify the coordinates where the species was found but specified the river, lagoon or municipality, the geo-reference was obtained through the Simulator of watershed flows "SIATL" version 2.1 (INEGI, 2010) by searching the location and getting the coordinates in degrees, seconds and minutes format and transformed to decimal degrees in an Excel spreadsheet.

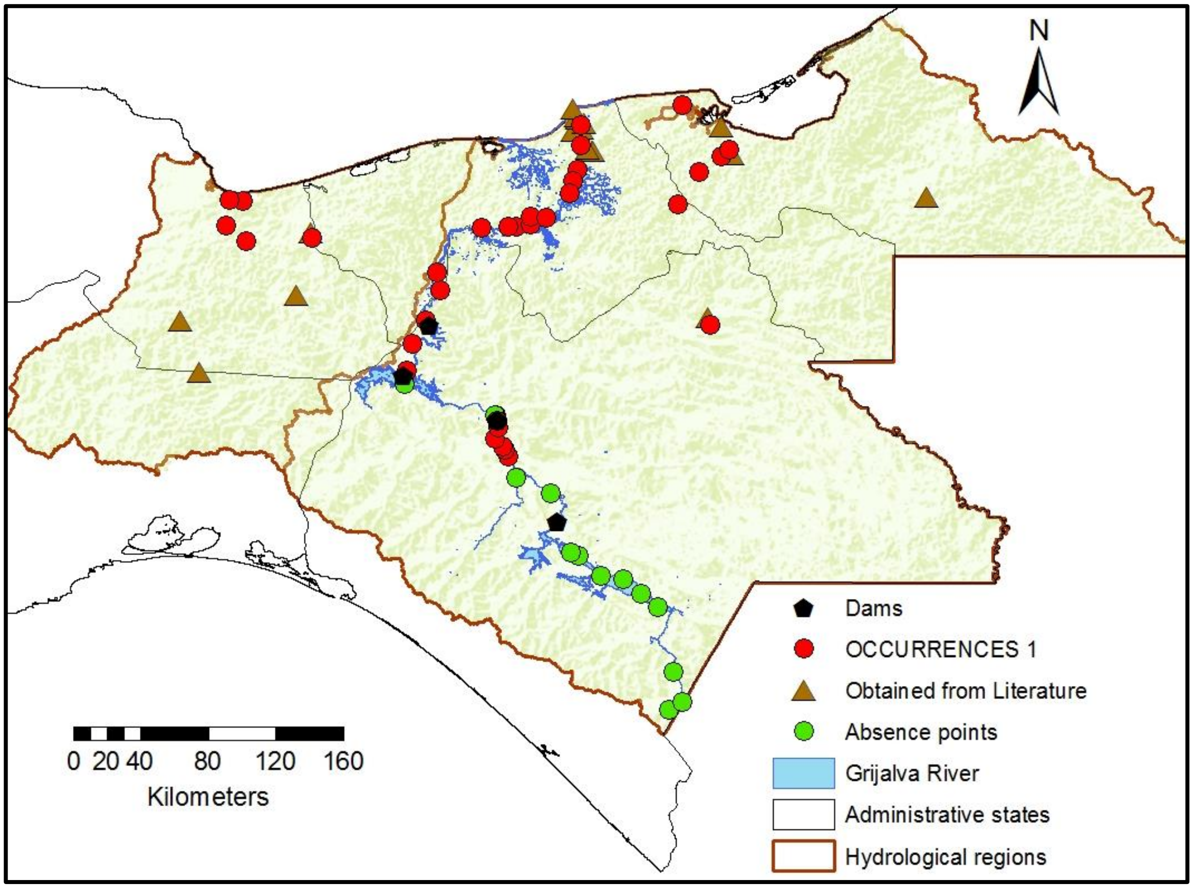

Figure 7. Map with occurrences of Loricariids in the study area.

5.2 Fishermen perception

A total of 25 interviews were held during the field work (Figure 8), 22 with local fishermen and three with presidents of fish cooperatives. The interviews with fishermen did not last more than five minutes each, while the interviews with presidents of fish cooperatives took up to 30 minutes. The fish cooperatives chosen were located one in Tabasco, in the Delta of Grijalva-Usumacinta hydrological complex, one on the way from Tabasco to Chiapas, near to "Peñitas dam" and the last in "Cañón del Sumidero" National Park. From the 22 interview to local fishermen, 10 were in Tabasco, 9 in Chiapas, 2 in Veracruz and one in Campeche. The interviews had two main objectives: first to confirm the occurrence of Loricariids in the area (in the places were the fish was not directly observed) and second to know about the impacts they perceived since Loricariids first sighting in the water bodies. If the presence of the fish was confirmed (question 1 below), a few exploratory questions were asked:

1. Have you seen this fish in the area? (while seeing a set of Loricariids photographs)
2. Do you know the name of the fish?

3. Since when have you seen it in the river? In which part?
4. Have you noticed any changes since the "fish" presence?
5. Could you give me an estimate of the proportion of this "fish" in the gills against native and commercial fish species?
6. What do you do when you catch them?
7. Do you use it for something or know someone who collects it? For which purpose?

Figure 8. Fisherman looking at Loricariid photographs

5.3 Set of predictors

According to a scientometric analysis based on papers published between 1991 and 2010, Barbosa *et al*., 2012 identified eight types of variables used to predict invasive species distribution. Climatic and topographic variables have been the most used (55.18 and 22.22%, respectively), followed by land cover, land use and vegetation (around 4% each) and aquatic, soil properties and human population and footprints. More than 80% of the studies focused on terrestrial environments, corresponding less than 20% of the reports to aquatic systems. Half of the studies held on freshwater environments used only terrestrial predictor variables, while about 35% used aquatic variables, such as salinity or dissolved oxygen and the rest of the studies combined both types of variables (Barbosa *et al*., 2012).

Some studies have obtained good results on habitat suitability for aquatic species using environmental and terrestrial variables. One is the case of *D geminata,* a single-celled alga found in water bodies modeled with bioclimatic variables because water chemistry variables are not yet available in GIS format (Kumar *et al*., 2009) and freshwater mussels in North America modeled based on land use and land cover (Hopkins, 2009).

The predictors used on this research belong to terrestrial and aquatic variables and are described as follow.

5.3.1 Climatic variables and DEM

A set of 19 bioclimatic variables of current conditions (for the period ~1950-2000) and a Digital Elevation Model were downloaded from the Worldclim Global Climate database (Hijmans *et al*., 2005) at a spatial resolution of 30 arcs (1 km) in ESRI grid format. The 20 variables were downloaded for the whole world to be able to extract the correspondent study area for modeling with occurrences of the native niche and for potential distribution (Table 2).

Table 2. Set of climatic and topographic variables

ID	Worldclim ID	Description
Tpa	Bio1	Annual mean temperature
Odt	Bio2	Mean diurnal range
Iso	Bio3	Isothermality
Et	Bio4	Temperature Seasonality (standard deviation *100)
Tmppc	Bio5	Min Temperature of Warmest Month
Tmppf	Bio6	Min Temperature of Coldest Month
Oat	Bio7	Temperature Annual Range (P5-P6)
Tpcll	Bio8	Mean Temperature of Wettest Quarter
Tpcs	Bio9	Mean Temperature of Driest Quarter
Tpcc	Bio10	Mean Temperature of Warmest Quarter
Tpcf	Bio11	Mean Temperature of Coldest Quarter
Pa	Bio12	Annual Precipitation
Ppll	Bio13	Precipitation of Wettest Month
Pps	Bio14	Precipitation of Driest Month
Ep	Bio15	Precipitation Seasonality
Pcll	Bio16	Precipitation of Wettest Quarter
Pcs	Bio17	Precipitation of Driest Quarter
Pcc	Bio18	Precipitation of Warmest Quarter
Pcf	Bio19	Precipitation of Coldest Quarter
Alt	Alt	Altitude

5.3.2 Other variables

5.3.2.1 Hydrology layers

In addition to the climatic and topographic variables, two hydrologic raster were added as predictors considering the direction of the natural flow of water and the accumulation of the flow according to elevation patterns. Flow direction and flow

accumulation rasters were derived from the Digital Elevation Model (previously obtained) using the ArcHydro extension in ArcGIS 10.1 ®.
The flow direction is a grid where each cell indicates the direction of the steepest descent from that cell (ESRI, 2011).

Flow accumulation grid is derived from the flow direction grid, the result is a raster of accumulated flow to each cell determined by accumulating the weight for all cells that flow into each downslope cell. Output cells that have a high flow accumulation are areas of concentrated flow, used to identify stream channels and the ouput cells with a flow accumulation of zero correspond to local topographic highs (ESRI, 2011).

5.3.2.2 Normalized Difference Vegetation Index (NDVI)

It is an estimate of the absorbed radiation through photosynthetic activity over the land surfaces. The scale varies from -1 to +1. Values near to zero (-0.1 - +0.1) normally represent barren areas of rock, sand or snow. Bare soil and sparse vegetation presents positive values although not very high. More positive values (close to 1) denote a greener area, meaning moist and well developed dense vegetation. Most negative values, near to -1, correspond to deep water. (Mitchell, 2002)

It has been used as a predictor for aquatic species, like the silver carp, where this variable had an influence on predicting its potential habitat (Poulos *et al*., 2012).

5.3.3 Categorical variables

5.3.3.1 Soil type

A map of Mexico with soil type classification was downloaded from geographic metadata catalog of CONABIO (SEMARNAP, 1998). The categorization is shown in Table 3.

Table 3. Categorization of the soil type layer obtained from SEMARNAP (1998). Description of each soil type according to FAO (IUSS, 2007)

ID	SOIL TYPE	DESCRIPTION
1	Solonchak	Soils that have a high concentration of soluble salts. Largely confined to arid and semi-arid climatic zones and coastal regions in all climates. International Nonproprietary Names are saline soils and salt-affected soils
2	Vertisol	Vertisols heavy clay soils, which are mixed with high proportion of swelling clays. These soils form wide and deep cracks from the surface when they dry down, what happens in most years.

3	Litosol	Are included in the Legosol classification, very shallow soils over continuous rock and extremely gravelly soils and / or stony. Leptosols azonal soils and are particularly common in mountainous regions
4	Regosol	Weakly developed soils in unconsolidated material
5	Fluvisol	Floodplains, coastal marshes
9	No data	
11	Cambisol	Materials derived medium to fine texture of a wide range of rocks. Environment: Land plains to mountainous in all climates; wide range of vegetation types. Including highly weathered soils.
14	Acrisol	From Latin *acer* very acidic. Highly weathered acid soils. Mainly old surfaces with hilly or undulating topography, in regions with a humid tropical / monsoonal, subtropical and warm temperate. The natural vegetation type is forest
15	Luvisol	Soils with higher clay content in the subsoil than in the first soil layer (horizon)
16	Gleysol	Soils with clear signs of influence of ground water; from the russian "gley": muddy mass. Areas depressed and low positions landscape with shallow groundwater.
18	Andosol	Typically, black soils of volcanic landscapes
19	Arenosol	Sandy soils
20	Nitisol	Red tropical soils, deep, well drained

5.3.3.2 Land use and vegetation

This layer was obtained from the classification of geographic metadata catalog of CONABIO (CONABIO, 2008). The classes are shown in Figure 22.

5.3.3.3 Drainage basins

It was downloaded from the Geographic metadata catalogue at a National level, scale 1:250,000 in a vector Esri shapefile format (CONAGUA, 2007). The basins file was created based on hydrological regions, meaning that the territorial area is defined according to their morphological, hydrological and orographic characteristics. According to that the watershed is considered as the basic unit for management of water resources. A hydrological region usually consists of one or more watersheds, so its limit is different to the political division into states, federal districts and municipalities (CONAGUA, 2007). Table 4 shows the categorization of the drainage basins layer.

Moratelli *et al*., 2011 have found drainage basin as an important predictor due to the biogeographic information that it contains, helping to indicate possible ecological barriers.

Table 4. Categorization of the drainage basins layer.

ID number	Sub-basin name	Hydrologic Region
1	Río Tonalá y Laguna del Carmen	Grijalva – Usumacinta
2	Río Coatzacoalcos	Coatzacoalcos
3	Río Usumacinta	Grijalva - Usumacinta
4	Río Chixoy	Grijalva – Usumacinta
5	Laguna de Términos	Grijalva – Usumacinta
6	Río Lacantún	Grijalva – Usumacinta
7	Río Grijalva – Tuxtla Gutiérrez	Grijalva – Usumacinta
8	Río Grijalva – Villahermosa	Grijalva – Usumacinta
9	Río Grijalva – La Concordia	Grijalva – Usumacinta

5.3.4 Physicochemical variables

As explained in the primary occurrence data section, physicochemical variables (pH, Temperature, Dissolved Oxygen (DO), Conductivity, Oxidation-Reduction Potential (ORP) and Total Dissolved Solids (TDS)) were measured directly using multiparametric probes. In Appendix 1 can be seen that 42 occurrence points had only records of four physicochemical variables (pH, temperature, DO and conductivity) while 33 had measurements of the complete set of six parameters. Definitions and interpretation of the physicochemical parameters are resumed in Table 5.

Table 5. Definition and practical interpretation of the physicochemical parameters measured. Definitions obtained from Aznar Jiménez (2000).

PHYSICOCHEMICAL PARAMETER	**DEFINITION / INTERPRETATION**
Temperature (°C)	The water temperature is of great importance in the development of the various processes performed. An increase in temperature changes the solubility of substances, increasing the dissolved solids and reducing gas.
pH	Is a measure of the concentration of hydronium ions ($H3O^+$) in solution. Water with pH values less than 7 are acidic waters which have values greater than 7 are termed basic and can cause precipitation of insoluble salts (scale). At pH measurements must be remembered that these undergo variations with temperature

	and that the values are for 20 ° C.
ORP (mV)	Oxidation-reduction potential (ORP) measures the ability of a lake or river to cleanse itself or break down waste products, such as contaminants and dead plants and animals.
Dissolved oxygen (mg/L)	Is a parameter indicative of the quality of water. The maximum value of OD is a parameter closely related to the water temperature and decreases with it. The maximum concentration of DO in the normal range of temperature is about 9 mg / L.
Conductivity (µS/cm)	Pure water behaves as an electrical insulator, with the substances dissolved therein which give the water the ability to conduct electric current. Is an indirect measure of the amount of dissolved solids
TDS	Is the sum of suspended particles and solubilized compounds

5.3.5 Correlation between variables

One of the problems for modeling is the correct selection of variables. For all the models exists the possibility not to find an adequate subset of variables when the complete set of variables are highly inter-correlated (Thuiller and Munkemuller, 2010). Thus, it is suggested to reduce multicollinearity among predictors (Elith *et al*., 2010; Guisan and Thuiller, 2005).

In order to estimate the correlation degree of the predictors, a Principal Component Analysis (PCA) was applied for the 26 variables (excluding the physicochemical) using the Principal Components geoprocessing tool in the spatial analysis section of ArcGis 10.1®. Due to the differences between the measurements units of the predictors, a pairwise comparison of the correlation factor (r) was made between the 26 predictors using the correlation matrix provided as a result of the PCA, instead of analyzing the eigenvalues of each variable (Jackson, 1993).

The highly correlated pair of variables were the ones with a ($r > 0.7$) (Poulos *et al*., 2012). Those pair of correlated variables were highlighted and evaluated to choose only a set of no correlated variables that represent the information contained in the variables that were not chosen (Appendix 2). The choice criteria was to keep the variable that contained more information when compared with the other variables in order to reduce the number of predictors and also based on the easiness for interpretation; for example, the altitude, which is highly correlated with eight other variables (seven of them also strongly correlated in between, because they are all temperature records) was chosen instead of picking seven of them. The subjective criteria for the predictors election based on interpretation was also adopted by Stohlgren *et al*., (2010) and the variables reduction by less interpretable predictor by (Poulos *et al*., 2012).

From the correlation analysis the number of predictor variables was reduced from 26 to ten, resumed in Table 6.

Table 6. Set of predictors selected from the correlation matrix to avoid multicollinearity.

Variable	Type of variable	Variable	Type of variable
1. Temperature Annual range	Continuos	2. Normalized Differential Vegetation Index	Continuos
3. Precipitation of coldest quarter	Continuos	4. Flow direction	Continuos
5. Isothermality	Continuos	6. Flow accumulation	Continuos
7. Altitude	Continuos	8. Soil types	Categorical
9. Drainage Basins	Categorical	10. Vegetation types	Categorical

6 MODELING

The modeling was based on two different statistical approaches, the decision factors include the predictor data resolution and availability, the objectives of the study and the occurrence data generated (Stohlgren *et al.*, 2010).

The first statistical model used is the maximum entropy (MaxEnt) distribution and the second is a Non-Parametric Regression Model (Hyperniche).

6.1 MaxEnt

MaxEnt version 3.3.3k was used for modeling species niche distribution (Phillips *et al*., 2004). It is a machine-learning general approach for modeling species distribution. The algorithm estimates a target probability distribution by calculating the most spread or maximum entropy distribution according to the constraints introduced, the so-called predictors (Phillips *et al*., 2006).

MaxEnt requires only presence data and environmental information for the study area and the data constraints could be either continuos or categorical. When modeling species distribution, the occurrences are the sample points, the geographical region of interest is the area where the distribution is defined and the environmental variables are the features. One of the advantages is that it can be used with complete information because it creates a "pseudo-absence" background. (Phillips *et al*., 2004)

This method was chosen because it has been used to model a broad range of species distribution giving high performance even with low number of localities and small sample sizes (Moratelli *et al*., 2011; Raedig and Kreft, 2011; Tognelli *et al*., 2009)

6.1.1 Modeling native distribution

According to Mandle *et al*., (2010), when climate niches are conserved across the native and introduced ranges, the comparison between climate in areas where the species have been introduced and its native range could provide valuable information regarding to spread and persistence, an important information for managing.

The spread potential of Loricariids in the Grijalva river basin based on their native distribution range was modeled using 211 presence points from South America. Two sets of predictor variables were used. The first model (NATIVE 1) used the nineteen environmental layers already obtained from worldclim (Hijmans *et al*., 2005). The second model (NATIVE 2) was done using four variables, one of them the altitude and other three climatic variables which were not inter-correlated according with the correlation matrix.

The objective to create models based on the native range was mainly to use them as a basis for the possible invasive range and to compare it with the potential distribution obtained using the presence records of the study area.

6.1.2 Modeling potential distribution

6.1.2.1 Occurrence points

The occurrence data were divided into two sets according to the source:

1. OCCURRENCES 1. Contain only the presence records measured directly and the ones obtained by the research group (identified in the Appendix 1 with a value of one in the "occurrence" column with asterix (*) in the "source" column). The

number of presence records is 33, but only 29 of them have valid values for all the predictors.

2. OCCURRENCES 2. Include all the presence points obtained for the study area: the directly obtained (used in the first set) and the literature and new records. The sum of the records is 51, but seven of them are lacking some environmental data, so the set is composed of 44 valid presence points.

Both sets of presence-only data were stored in a comma separated values (.csv) format, available in Excel, and include the species name, geo-reference in a longitude (x) and latitude (y) decimal degrees. (Transformed from the projected coordinate system WGS_84_UTM zone 15 Nord).

6.1.2.2 Set of terrestrial variables

Although a correlation analysis was carried out to reduce the number of variables, all the 26 layers were processed to be used for exploratory runnings to observe if multicollinearity between predictors and the use of categorical variables have visible effects in the prediction capacity of MaxEnt. For visualization purposes and to prove the prediction capacity of the model in a greater area, the layers were "extracted by mask" to an extend that includes not only the Grijalva-Usumacinta hydrologic complex but also the Coatzacoalcos region, which is located in the western part of the Grijalva river. The rectangular box of the extend is 19.126850 top, 15.260368 bottom, -95.742550 to the left and -89.367805 to the right, all the occurrence points are within this area. The cell size of all the predictors was homogenized to the original resolution of the nineteen environmental variables (0.008333° or ~1km^2).

For comparison reasons, four different subsets of predictors were done, and combined with two groups of occurrences previously explained; the different combinations are represented and labeled in the Table 7. The aggrupation of the variables were done searching for the best set of predictors and, as mentioned before, to observe if there are important differences in the predicted area using high correlated variables versus no correlated and using continuous compared with the combination of continuous and categorical variables.

The first set include all the variables, while the second uses only environmental continuous variables obtained from worldclim (Hijmans *et al*., 2005), both sets contain highly correlated variables.

The third group was made from the selection of those variables showing the least correlation, and the last one was obtained after running the third set to exclude continuous variables that had negative gain when used in isolation (jackknife test) and all the categorical predictors (After Jackknifing)

Table 7. Matrix representation of the different model runs using three different set of predictors. Every model combination is labeled by the term POTENTIAL followed by a consecutive number. The numbers below (for row) and after (for column) indicate how many variables or occurrences were used for the models.

	All the variables (26)	Worldclim (19)	No high correlated variables (10)	After Jackknifing (6)
OCCURRENCES 1 (29)	**POTENTIAL 1**	**POTENTIAL 2**	**POTENTIAL 3**	**POTENTIAL 4**
OCCURRENCES 2 (44)	**POTENTIAL 4**	**POTENTIAL 6**	**POTENTIAL 7**	**POTENTIAL 8**

6.1.2.3 Set of aquatic variables: physicochemical parameters.

In order to be able to run the physicochemical variables in Maxent, continuous layers of the six physicochemical parameters plus altitude were created.

As the variables are water parameters, the spatial extend of the modeling was restricted only to the rivers belonging to the Grijalva-Usumacinta and Coatzacoalcos region. A shapefile of all the rivers for both regions was generated by “merging” the individual shapefiles (data downloaded from (INEGI, 2010) of each river into one, using the “merge” tool in the Arctool box of ArcGis 10.1® . A buffer of 500 meters was applied to the file in order to avoid “null” value cells in the further conversion from feature to raster with an adjusted cell size of 1km^2 . This resulting raster of the rivers will be used as a mask to delimitate the spatial extend of the physicochemical layers.

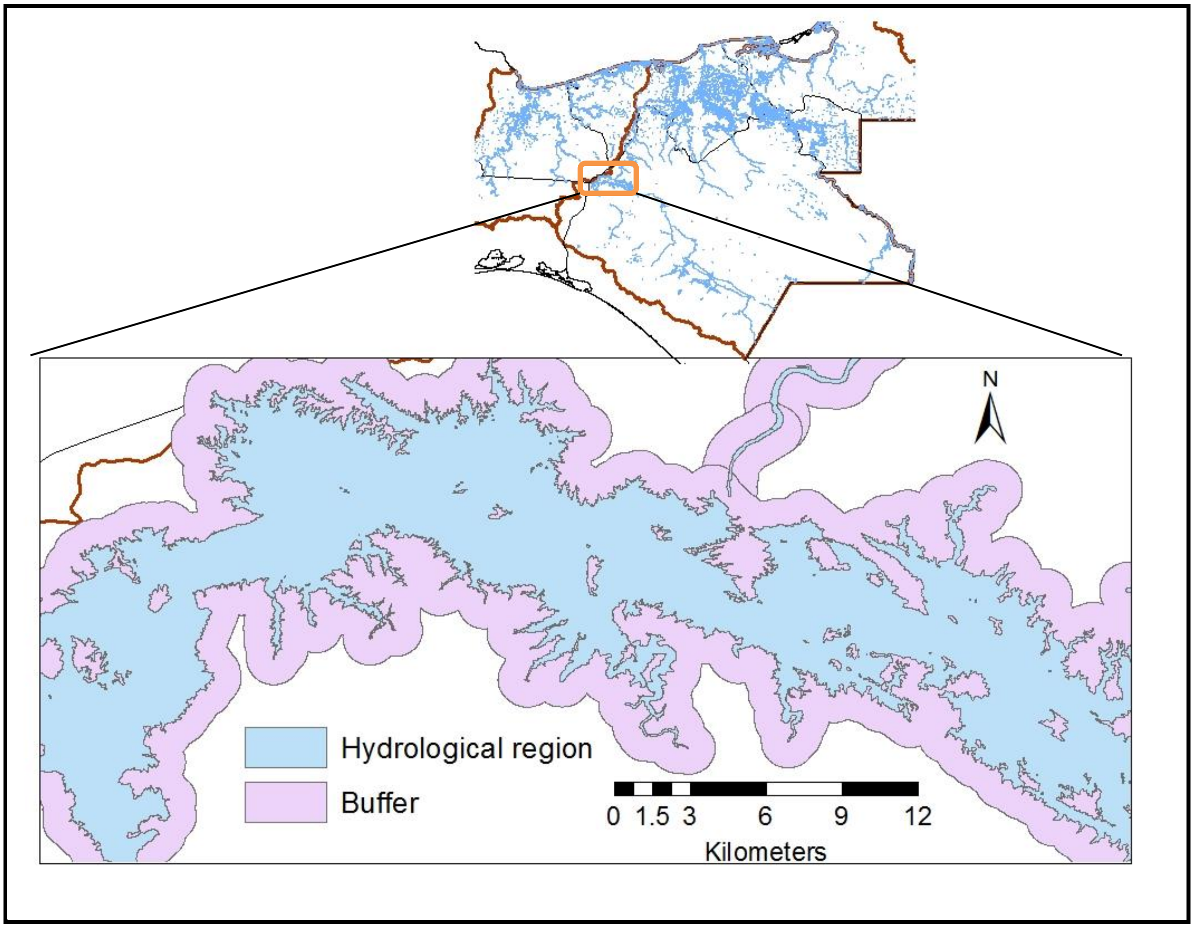

Figure 9. Zoom into Malpaso dam to show the effect of buffering.

All the physicochemical values measured are only punctual (measured in one point), thus they have to be converted into continuous raster. An Inverse distance weighted (IDW) interpolation method was used which generates values for every pixel in the delimitated region. The IDW interpolation method has already been applied to generate coverage layers for physicochemical, biological and chemical parameters of water reservoirs to model the potential distribution of phytoplankton (Ibarra-Montoya *et al*., 2010). The range values of the output layers are limited to the values used for interpolation. A total of 42 measurements were used as an input for the pH, temperature, dissolved oxygen and conductivity, while only 33 were available for the ORP and total dissolved solids layers.

These predictors were also combined with the two occurrence groups, leading to two models, the aim was to analyze the model response (species distribution) varying the number of occurrences.

For further identification, the models were named as follow:

- Physicochemical model 1 (**PCM 1**): 29 occurrences and seven physicochemical parameters.
- Physicochemical model 2 (**PCM 2**): 44 occurrences and seven physicochemical parameters.

6.1.2.4 Settings

All the maxent models were run under the same settings to be able to compare them. The “autofeatures” mode and default settings were selected (Phillips and Dudík, 2008). “Cumulative” output was chosen because it is easier to interpret than the “raw” output, which have extremely small values, because the sum of all of cells in the grid must be 1 (Phillips *et al*., 2006). The “cumulative” representation gives percentage values for every pixel, calculated from the sum of the probabilities of that pixel and all the other pixels with lower or equal probability and multiplied by 100 (Phillips *et al*., 2006). The configuration of the models was designed to use 75% of occurrence data for training and 25% for test (Anderson *et al*., 2002). The default parameters for MaxEnt were used to generate five replicates by bootstrap with a “threshold” prevalence of 0.5. The prevalence of the species means the proportion of occupied sites in the landscape (Elith *et al*., 2011). The create response curve option was also activated for further analysis.

6.1.2.5 Validation

To verify the accuracy of the niche models, two tests were performed using Maxent according to threshold dependency. For both methods it was necessary to separate a percentage of the occurrence data for testing, in all cases 25% of the occurrences were randomly selected for this purpose.

The threshold dependent testing transforms the continuous numerical value of each pixel into binary values according with the fixed threshold to define the presence/absence. The actual version of Maxent (3.3.3k) has eleven different approaches for thresholding. When the data has been converted into binary values, the program execute a one-tailed binomial test to determine if the model prediction is better than random (Anderson *et al*., 2002), in all runs the number of test samples was less than 25 meaning that the exact one-sided binomial probabilities (p) were calculated for each of the thresholding rules as described in Phillips *et al*., (2006). This significance test includes the omission rate (segment of the test localities that are in an area that was not predicted to be suitable for the species) and the proportional predicted area through the fraction of pixels predicted as suitable for species. In

Appendix 10 are summarized the results for model POTENTIAL 4. To test accuracy it was analyzed the proportion of test points that are in the area where presence was predicted (Anderson *et al*., 2002).

The threshold independent test was made using the receiver operator curve modified by (Phillips *et al*., 2006) for presence-only data (Figure 10). It consists on analyzing the curve obtained from plotting sensitivity (y-axis) against 1-specificity (x-axis) (Thuiller *et al*., 2003), which could be interpreted as the relation between the proportion of correctly predicted observations by the model (true positive rate) and the proportion grid squares where the species was not observed but where the model predicts presence (false positive rate) (Ortega-Huerta and Peterson, 2008)). The area under the ROC curve is the probability that the classifier correctly predicts the presence and absence using random examples and for a perfect adjustment the AUC value is equal to 1, while values less or equal to 0.5 indicates that the model does not perform better than random (Phillips *et al*., 2006, 2004). Due to the nonparametric calculation of AUC it is recommended for ecological applications (Rödder *et al*., 2009) and thus used in many studies (Moratelli *et al*., 2011; Nabout *et al*., 2010; Poulos *et al*., 2012; Raedig and Kreft, 2011)

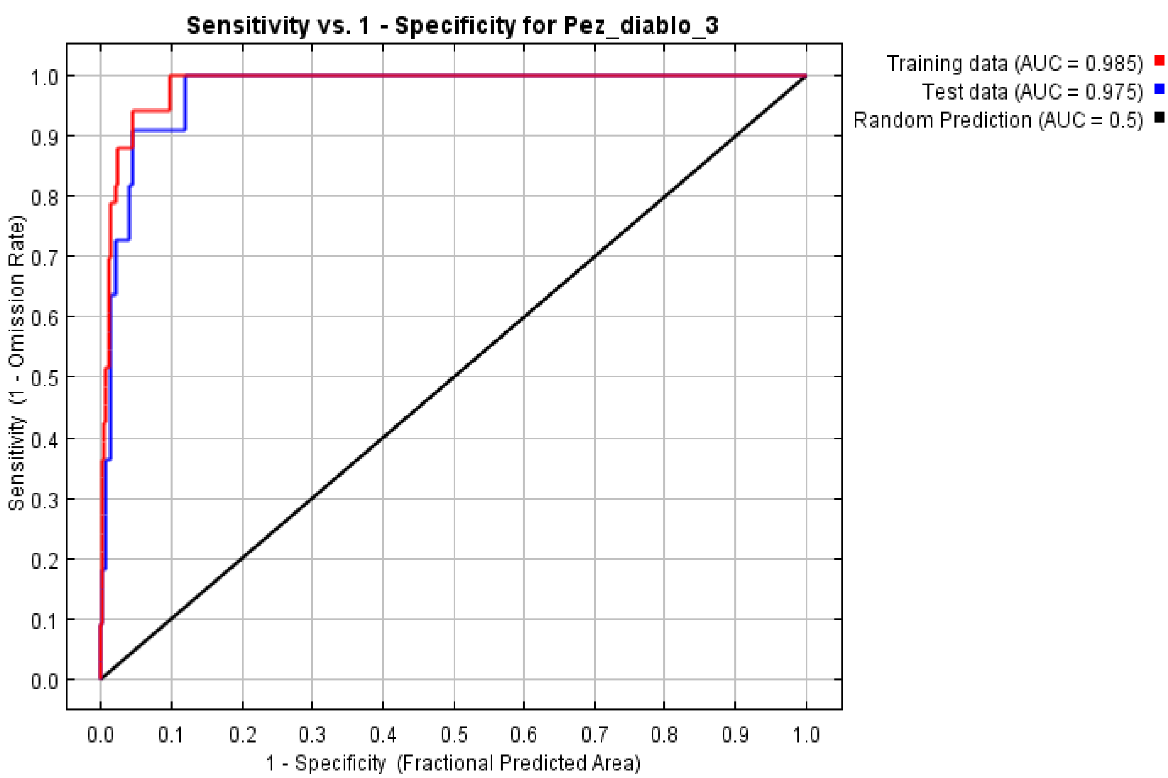

Figure 10. Receiver operation characteristic (ROC curve) of one of the models for Loricariids.

The final models were evaluated to meet the criteria of an AUC > 0.7 (based on the independent threshold test) and a significance value ($p < 0.05$) for any of the 11 binomial test computed (Pawar *et al*., 2007).

6.1.2.6 Predictors evaluation

In order to analyze the individual contribution that each variable gives to the model, the Jackknife of regularized training gain was selected. The Jackknife test training gain of each predictor as if the model was run in isolation and then compares it to the training gain of all the variables (Elith *et al*., 2011)

6.2 Hyperniche

Hyperniche is a software package that applies the concept of a non-parametric multiplicative regression model (NPMR). It was used to obtain the species response functions as described by McCune (2004). This approach was used to complement the results of the models based on physicochemical parameters obtained by Maxent. The response curves show how the Loricariids presence probability changes along the different values of the physicochemical parameters. The preferred ranges for Loricariids observed in the response curves contribute to know the water conditions suitable for Loricariids occurrence. Additionally, this information contributes to relate the environmental conditions with physiological adaptation of the fish species in the new range of distribution.

6.2.1 Occurrence points

The occurrence points for modeling with Hyperniche are based on presence and absence data. It requires a response and a predictors file as input data. Both of them were stored in Excel format (.xls) and Hyperniche automatically transformed them into a (.wk1 format), an input format required to run the model. The response file includes the occurrences of the species in a binary code, 1 assigned for presence and zero for absence. The predictors file was generated with the results of the physicochemical measurements as quantitative values; the program also supports categorical data.

The run of the algorithm was done with 33 presence/absence points, corresponding to records that had values for the six physicochemical variables (Appendix 1).

A free search to fit the models was done. The model with best fit according to the number of predictors was chosen. Response curves for each predictor were obtained as graphics.

6.2.2 Validation

A leave-one-out cross validation was applied during the search of the best model, meaning that the choice of the predictors and their tolerances are based on the cross-validation result. This procedure was made to analyze the predictive capacity of the model (McCune, 2004)

6.3 Models comparison

6.3.1 Models with environmental data

To compare the native and potential species distribution models, a decision matrix with three important results was elaborated (Nabout *et al*., 2010; Poulos *et al*., 2012; Rödder *et al*., 2009; Tognelli *et al*., 2009). The matrix includes:

- Mean value of the area under the curve (AUC) for each occurrence-predictor model. This is the result of fivefold runs using 25 percent of the occurrences for training and 75 percent for testing.
- Predictors that showed more gain in the model.
- Percentage of predicted distribution area.

The AUC values and the predictors gain are results of the Maxent model runs; however the percentage of predicted area was calculated in ArcGIS 10.1®. The Maxent outputs are continuous layer maps that represent geographically the predicted species distribution as a cumulative probability for each pixel in a percentage format. These maps were transformed into binary values maps applying a fixed arbitrary value of prevalence threshold (Manel *et al*., 1999; Pearson, 2007) , in this case equal or higher than 25. The new values of the maps are zero and one. The cells having a value of one are those that have equal or more than 25 percent of presence probability, while pixels with a value of "zero" are considered as predicted absence places for Loricariids. With the number of cells that predicted presence according to the binary classification for each model and the total study area, the percentage of the predicted presence area was calculated as follows:

$$\%\ of predicted\ presence\ area = \left(\frac{No. cells\ predicted\ presence}{Total\ number\ of\ cells\ study\ area}\right).100$$

Having all the values, comparisons between models were done.

To analyze the effect of the variables used as predictors the following comparison were done:

1. NATIVE 1 & NATIVE 2
2. **POTENTIAL 1; POTENTIAL 2; POTENTIAL 3 AND POTENTIAL 4**
3. **POTENTIAL 5; POTENTIAL 6; POTENTIAL 7 AND POTENTIAL 8**
4. **PHYSICOCHEMICAL 1** & **PHYSICOCHEMICAL 2**

The effect of the number and quality of occurrences used for the models was analyzed through the following comparisons:

1. **POTENTIAL 1** & **POTENTIAL 5**
2. **POTENTIAL 2** & **POTENTIAL 6**
3. **POTENTIAL 3** & **POTENTIAL 7**
4. **POTENTIAL 4** & **POTENTIAL 8**

The native distribution models were contrasted with the potential distribution models generated.

Models using physicochemical parameters were compared with the results obtained from hyperniche.

7 RESULTS

The results of modeling with Maxent are divided in three parts: potential distribution using occurrences in the native range of distribution, potential distribution with occurrences of the invaded range and potential distribution using physicochemical parameters.

7.1 Models using native occurrences

7.1.1 Species distribution maps

The predicted probability distributions of the two models generated using occurrences of the native area are shown in (Figure 11). There are remarkable differences between the predicted area when using all bioclim variables (NATIVE 1) and using only a selected set of no-highly correlated environmental layers combined with altitude (NATIVE 2). NATIVE 1 predicted high presence probability for Loricariids in the Grijalva-Usumacinta Delta, eastern part of Tabasco State, in the limits with Belize. A small part surrounding Peñitas dam was also predicted as a potential invaded region. The total area that has suitable environmental conditions for Loricariids establishment in model NATIVE 1 is about eight percent, while for model NATIVE 2 it is more than 50% of the total study area (Table 8). The Gulf Coastal Plain is the most affected area in accordance with NATIVE 2 model, the presence prediction includes most of the Tabasco State territory, southeastern Veracruz, western Campeche and northern Chiapas.

Figure 12 contain a presence/absence map predicted for both native models. They were obtained by fixing a threshold of prevalence for the species when the presence probability is equal or greater than 25 percent. It can be observed that the area predicted by NATIVE 1 is totally included in NATIVE 2 prediction.

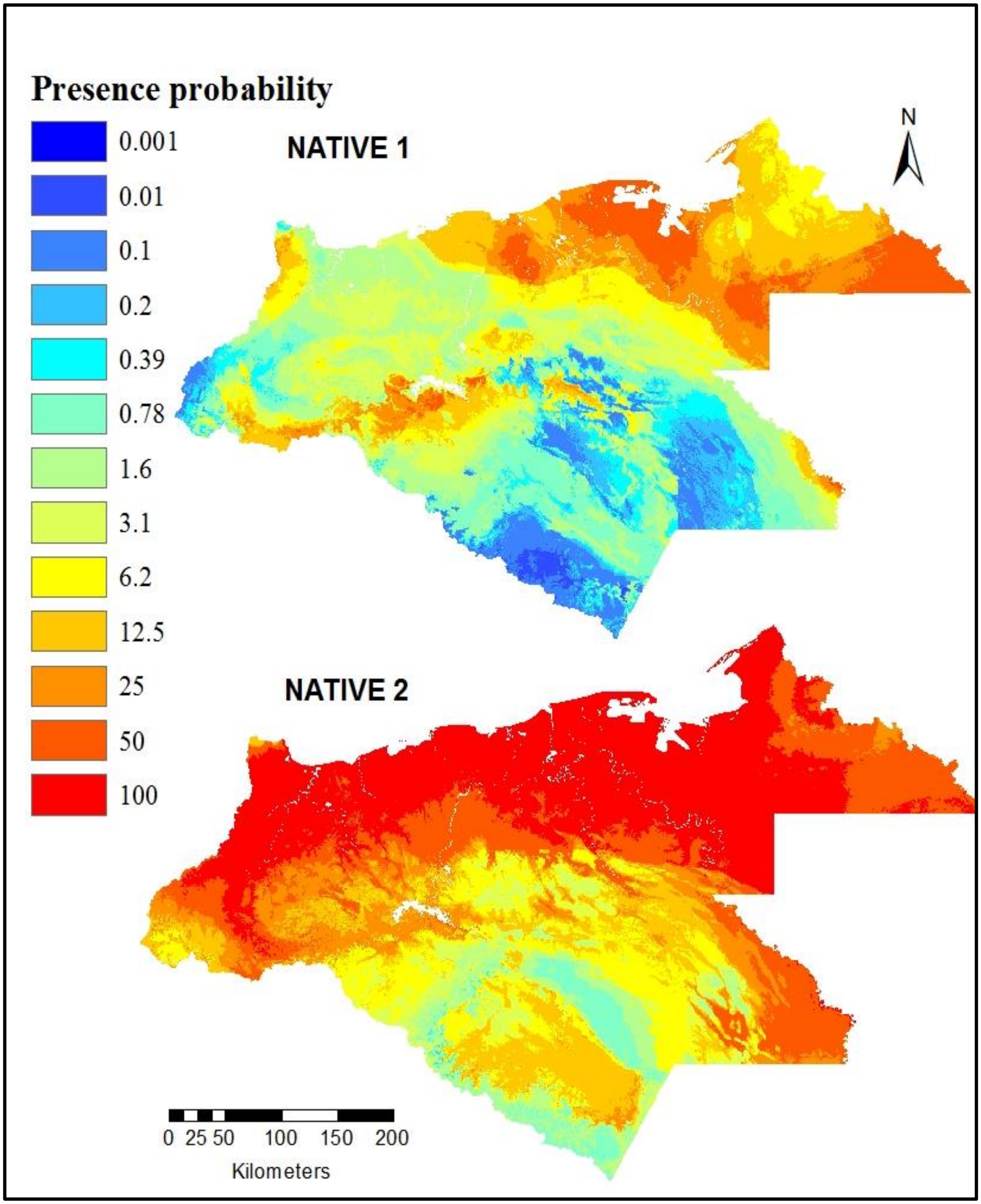

Figure 11. Maxent probability distribution using occurrences in the native range.

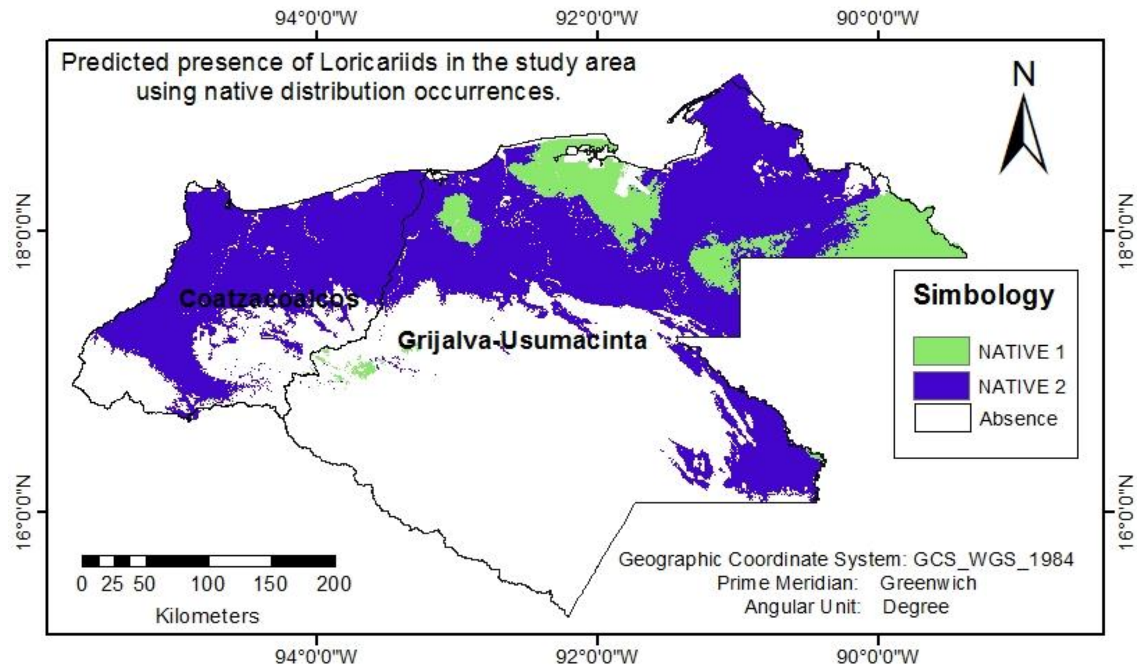

Figure 12. Comparison between suitable areas for Loricariids predicted by NATIVE 1 and NATIVE 2 models.

7.1.2 Validation

Geographic distribution models for Loricariids using occurrences of the native distribution range and worldclim variables as predictors showed good accuracy considering the mean AUC value of the ROC curves obtained for training and test, reported in Table 8 (0.8<AUC>0.9).

Table 8. Results for the distribution models using occurrences of the native range. AUC mean values for training (AUC Trai) and test (AUC Test). Predictors that have highest gain for each model. Percentage of area considered as suitable for Loricariids (presence probability ≥ 25)

Worldclim		**After Jackknifing**	
NATIVE 1		NATIVE 2	
AUC Trai	***AUC Test***	***AUC Trai***	***AUC Test***
0.96248	0.86152	0.86564	0.79464
Predictor	***Gain***	***Predictor***	***Gain***
bio16	13.8	altitude	40.9
bio2	12.4	bio19	30.2
bio12	9.5	bio7	19.2
bio10	9	bio3	9.4
bio4	8		

% Area predicted as suitable	7.80	**% Area predicted as suitable**	51.09

7.1.3 Predictors

According to the Jackknife operator, the variable with more gain in isolation for NATIVE 1 is the precipitation of the wettest quarter (bio16), while the temperature seasonality (bio4) is the predictor that decreases more the gain when it is omitted (**¡Error! La autoreferencia al marcador no es válida.**). The set of the five variables with highest gain represent less than 60% of the total gain of the model.

For NATIVE 2, altitude is the variable that contributes about 40% of weight in the model, followed by precipitation of the coldest quarter (bio19) and annual oscillation of the temperature (oat). The sum of the gain of the three variables accounts for 90% of the total gain model (Figure 14).

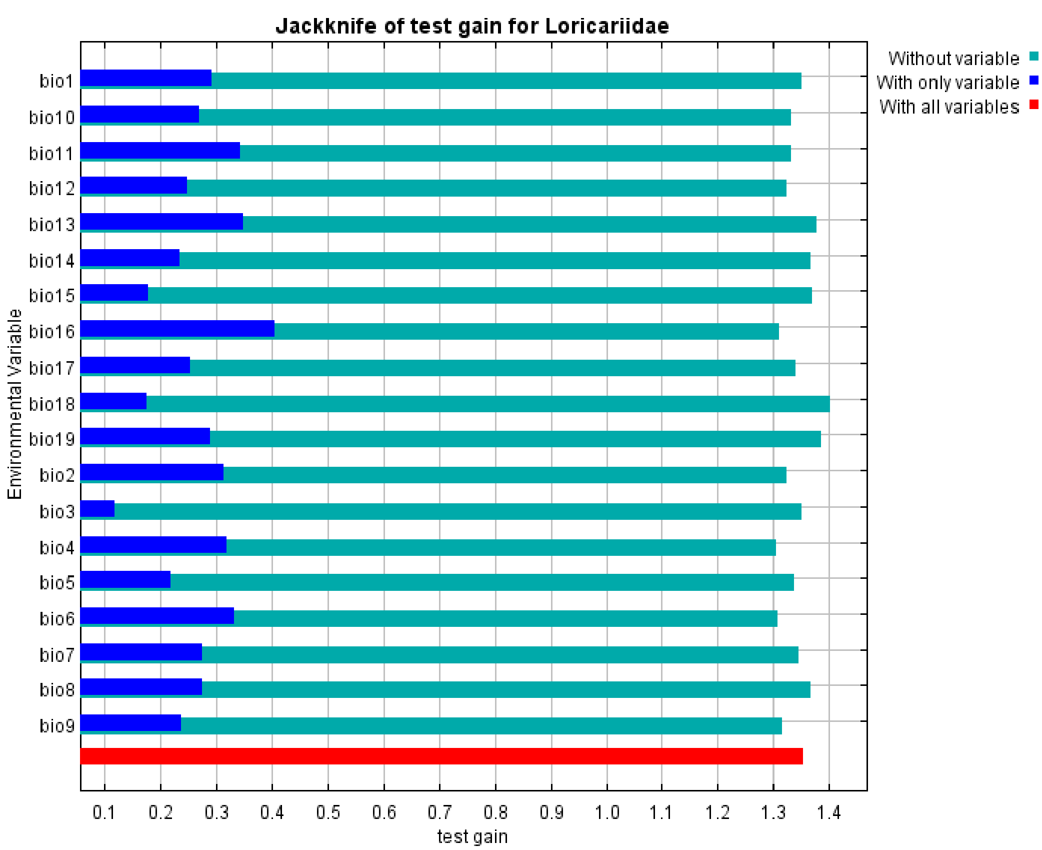

Figure 13. Jackknife test results for model NATIVE 1.

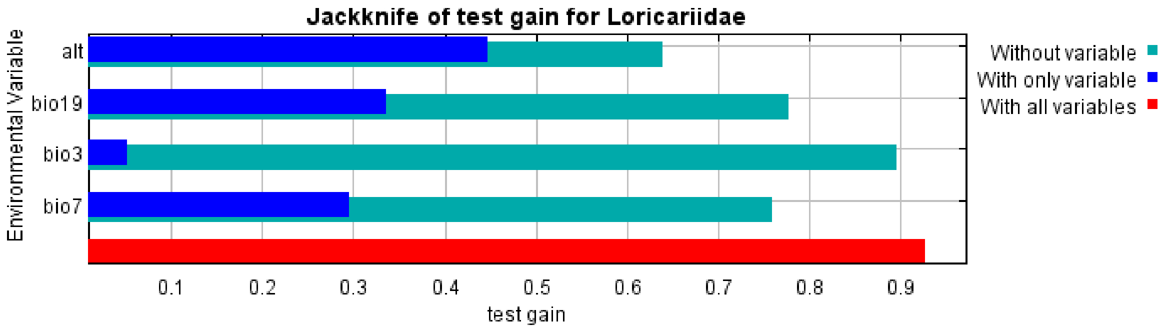

Figure 14. Jackknife test result for model NATIVE 2.

7.2 Models using invaded ranges

A total of eight species distribution maps were generated using occurrences of Loricariids in invaded ranges. The results are divided in two sets according to the quality of the occurrence data. Each group contains four models (from 1 to 4 and from 5 to 8).

7.2.1 Species distribution maps (POTENTIAL 1 TO POTENTIAL 4)

The predicted potential distribution corresponding to the first two models are shown in Figure 15 and POTENTIAL 3 & 4 in Figure 16. All the models identify high probability of Loricariids presence (more than 50%) in the central and northern part of Tabasco. This area is mainly a floodplain and includes also “Pantanos de Centla Wetlands” biosphere reserve located in the Delta of Grijalva-Usumacinta hydrological complex. For POTENTIAL 1 and POTENTIAL 3, the suitable habitat for Loricariids does not go further than the National Park “Sumidero Canyon” located in Chiapas, while for POTENTIAL 2 and POTENTIAL 4 high probability of Loricariids presence is found along the Grijalva River until the limit to Guatemala (Grijalva River upper part).

Having used the same set of occurrences (OCCURRENCES 1) to construct the models, the differences in the potential distributions obtained depend on the number and type of variable used as predictor.

The binary maps created for each of the models are compared in Figure 17. Using this presence-absence classification the area predicted as presence for Loricariids is summarized in Table 9. There are clearly similitudes between the predicted area of POTENTIAL 1 (%Area=4.57) and POTENTIAL 3 (%Area~5%) and POTENTIAL 2 (%Area=18.5) and POTENTIAL 4 (%Area~17). Although the percentages are very close, a further comparison was made to find out the area that both pair of models share between them. This was done, creating a new map representing the cells that were predicted as presence (value=1) in the two maps.

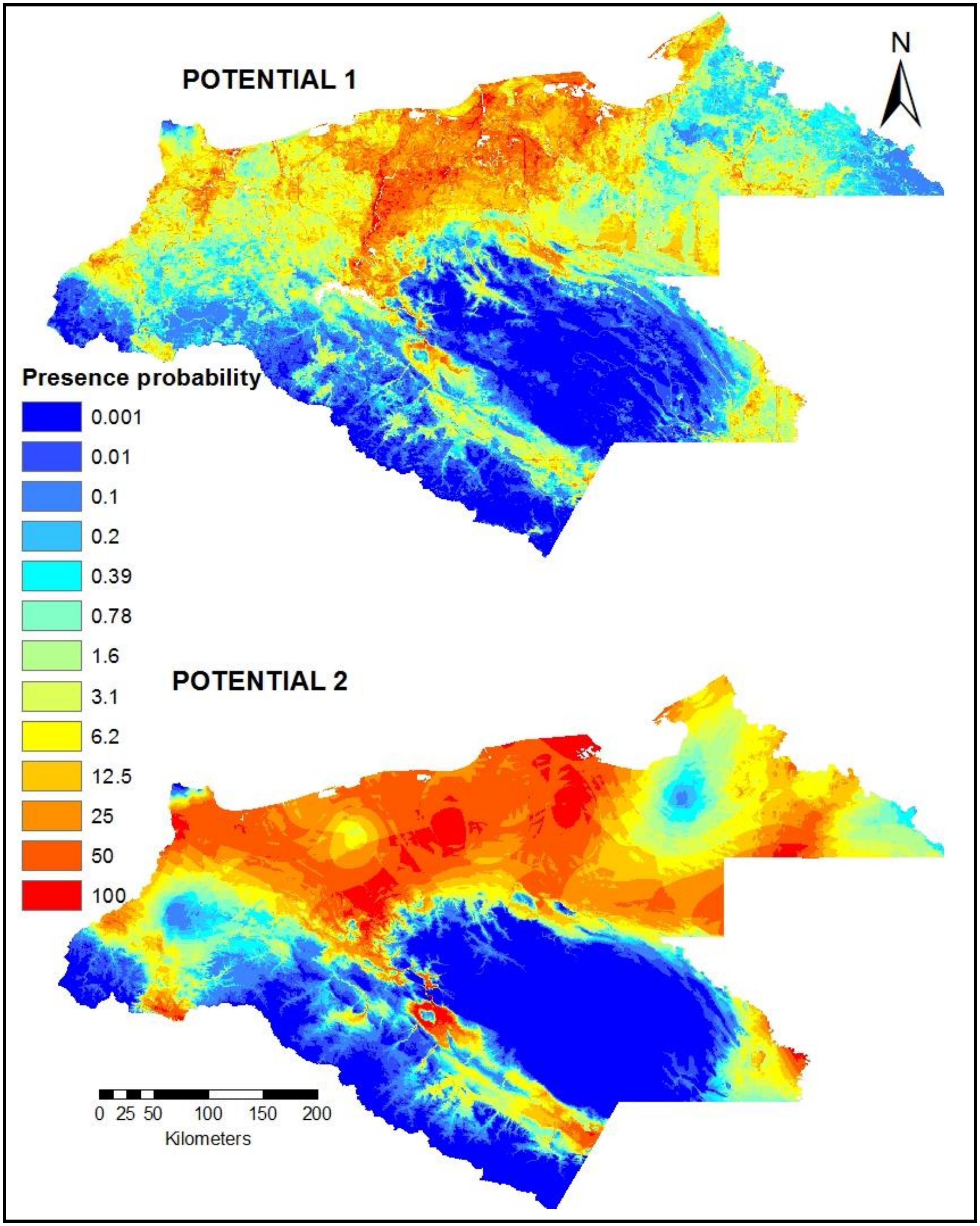

Figure 15. Maxent potential predicted distributions of POTENTIAL 1 & 2, using directly obtained occurrences of the study area (OCCURRENCES 1).

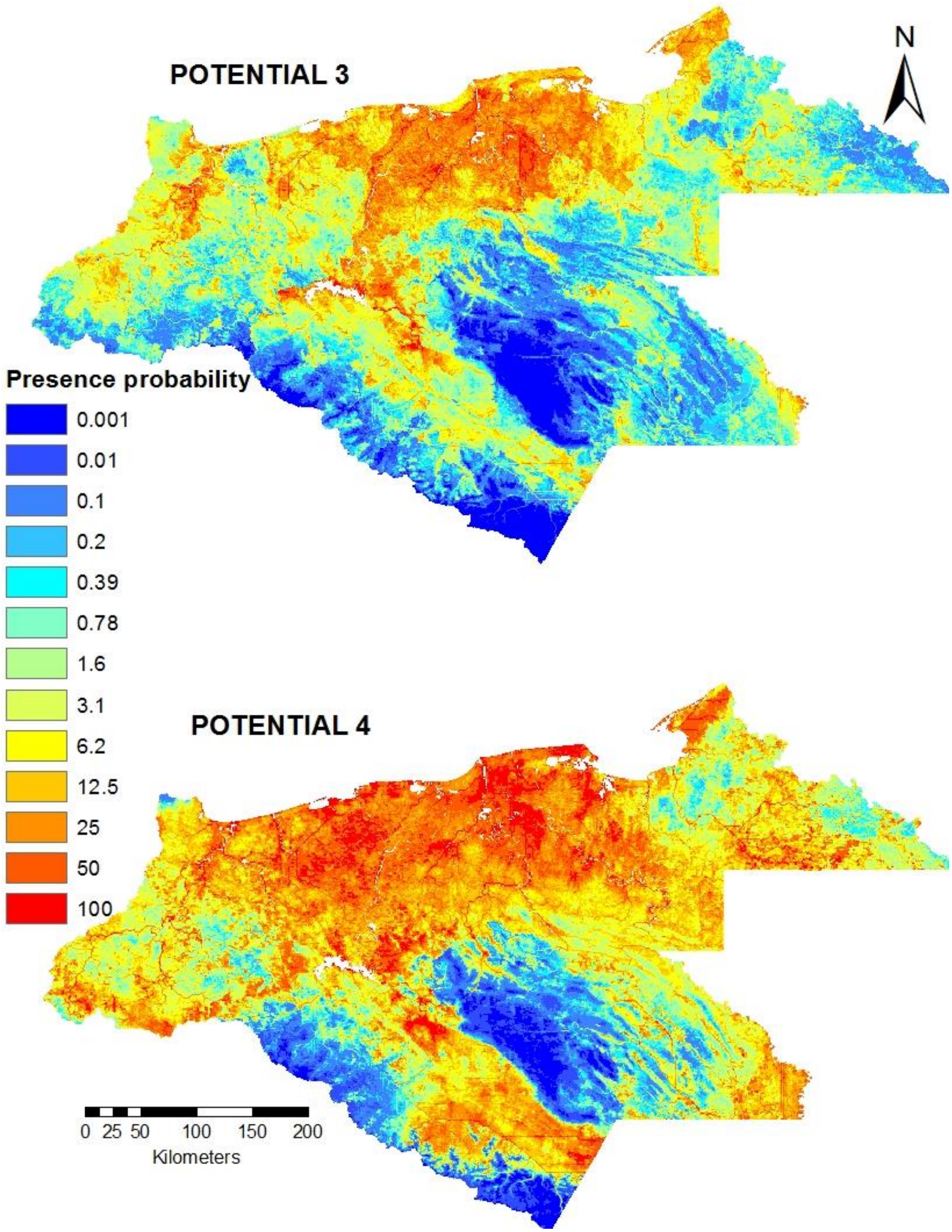

Figure 16. Maxent potential predicted distributions of POTENTIAL 3 & 4 using directly obtained occurrences of the study area (OCCURRENCES 1).

Table 9. Matrix summarizing the results of the potential models generated with occurrences of Loricariids on invaded ranges. AUC values are the mean values for a five-fold models run. All AUC values in Appendix 8. For other predictors and gains see Jackknife test results in Appendix 9.

	ALL THE VARIABLES		WORLDCLIM		NO HIGH CORRELATED		AFTER JACKKNIFING	
OCCURRENCES 1 (Directly obtained)	**POTENTIAL 1**		**POTENTIAL 2**		**POTENTIAL 3**		**POTENTIAL 4**	
	AUC Trai	***AUC Test***	***AUC Trai***	***AUC Test***	***AUC Trai***	***AUC Test***	***AUC Trai***	***AUC Test***
	0.9876	0.9588	0.9574	0.9164	0.9826	0.943	0.9256	0.8806
	Predictor	***Gain***	***Predictor***	***Gain***	***Predictor***	***Gain***	***Predictor***	***Gain***
	soil type	17.6	tpcc	37	soil type	18.3	ndvi	37.8
	ndvi	17.3	tpcs	19	altitude	15.6	flowacc	19.3
	basin	14	tpcf	7.6	veget	15.2	altitude	19.3
	tpcc	13.1	iso	7	ndvi	15	iso	18.6
	veget	11.9	tmppc	6.1	basin	14.3	pcf	4.3
	% Area predicted as suitable	4.57	**% Area predicted as suitable**	18.50	**% Area predicted as suitable**	4.96	**% Area predicted as suitable**	16.97
OCCURRENCES 2 (Directly obtained + Literature)	**POTENTIAL 5**		**POTENTIAL 6**		**POTENTIAL 7**		**POTENTIAL 8**	
	AUC Trai	***AUC Test***	***AUC Trai***	***AUC Test***	***AUC Trai***	***AUC Test***	***AUC Trai***	***AUC Test***
	0.9768	0.9272	0.947	0.9032	0.9566	0.9186	0.9226	0.9036
	Predictor	***Gain***	***Predictor***	***Gain***	***Predictor***	***Gain***	***Predictor***	***Gain***
	ndvi	16.5	tmppf	28.3	veget	24.8	ndvi	38.2
	basin	13.3	tpcc	27.7	altitude	18.5	altitude	36.9
	altitude	13	tpcs	8.9	ndvi	17.9	iso	8.9
	veget	11.6	tpa	5.8	basin	13.8	flowacc	7.8
	tmppf	9.2	ppll	4.2	soil type	9.8	pcf	4.7
	% Area predicted as suitable	6.64	**% Area predicted as suitable**	14.82	**% Area predicted as suitable**	7.86	**% Area predicted as suitable**	15.13

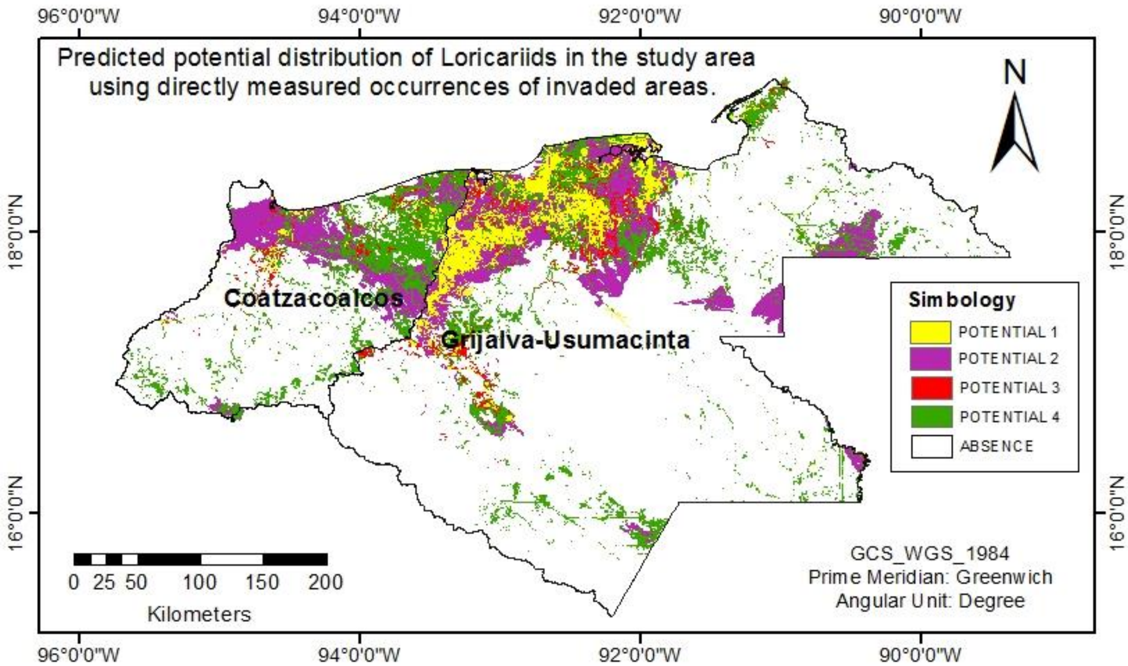

Figure 17. Presence-Absence map of Loricariids comparing four models with different sets of variables as predictors. The prevalence threshold used was 25.

7.2.1.1 Validation

The accuracy of the four models obtained range from good (AUC > 0.8) to very good (AUC >0.9) for training and test AUC, as it could be seen in Table 9.

7.2.1.2 Predictors

The results of the variables showing more gain in the models are concentrated in Table 9. Soil type, basin and vegetation are predictors that explain more than 40 percent of the total gain for models POTENTIAL 1 and POTENTIAL 3. Normalized Differential Vegetation Index is a variable that shows high gains in all the models that included it, mainly in POTENTIAL 4, representing more than 35% of the total gain. Models POTENTIAL 1 and POTENTIAL 3 are very similar. The differences are the substitution of tpcc present in POTENTIAL 1 by altitude in POTENTIAL 3 and the gain value for the predictors. For POTENTIAL 2, the variables that better predict are related with temperature. Flow accumulation is a variable that was used in three different sets of predictors, but it had important gain only for POTENTIAL 4.

7.2.2 Species distribution maps (POTENTIAL 5 to POTENTIAL 8)

The second group of species distribution models is represented in Appendix 4 . The models were made with available occurrences obtained directly and from literature (OCCURRENCES 2).

The predicted suitable area for Loricariids is comparatively similar to that seen in the models described above (POTENTIAL1-POTENTIAL4), but more spread. The western part of Tabasco and the southeastern part of Veracruz are included as areas of medium to high presence probability (probability≥25). The models found only certain areas of the medium and upper part of the Grijalva River with high probability of Loricariids presence, this are the National Park "Sumidero Canyon" and a small area in the limits with Guatemala.

The percentage of area predicted as presence for Loricariids in models POTENTIAL 6 (%Area=14.8) and POTENTIAL 8 (%Area=15.1) doubles the value obtained with POTENTIAL 5 (%Area=6.6) and POTENTIAL 7 (%Area=7.8), respectively (Table 9). A graphic representation of the presence-absence models are shown in Figure 18. The similitudes between POTENTIAL 6 & 8 and POTENTIAL 5 & 7 are due to the inclusion or exclusion of categorical variables in the predictors set.

7.2.2.1 Validation

The models obtained very good accuracy based on the AUC value for training and test. Although there are slightly differences between the values, all of them ranged an area under the curve higher than 0.9 (Table 9). The models using categorical variables (POTENTIAL 5 & 7) show a better adjustment of the AUC values.

7.2.2.2 Predictors

The variables that contribute with more information for the models POTENTIAL 5 and POTENTIAL 7 are NDVI, altitude, basin and vegetation, each of them with a gain higher than ten. Also for POTENTIAL 8 the variables altitude and NDVI are the most important, representing more than 75 of the total gain of the model.

The response of the model POTENTIAL 6 is based on environmental layers related with temperature.

By adding the gain of the five most important variables for each model shows a tendency to increase the gain of each variable when the number of predictors used decreases. The approximate values are 64, 75, 85 and 97, for POTENTIAL 5, 6, 7 and 8, respectively (values obtained adding the gain values reported in Table 9. This means that the amount of information provided by the predictive model is based on all variables and then evaluated individually.

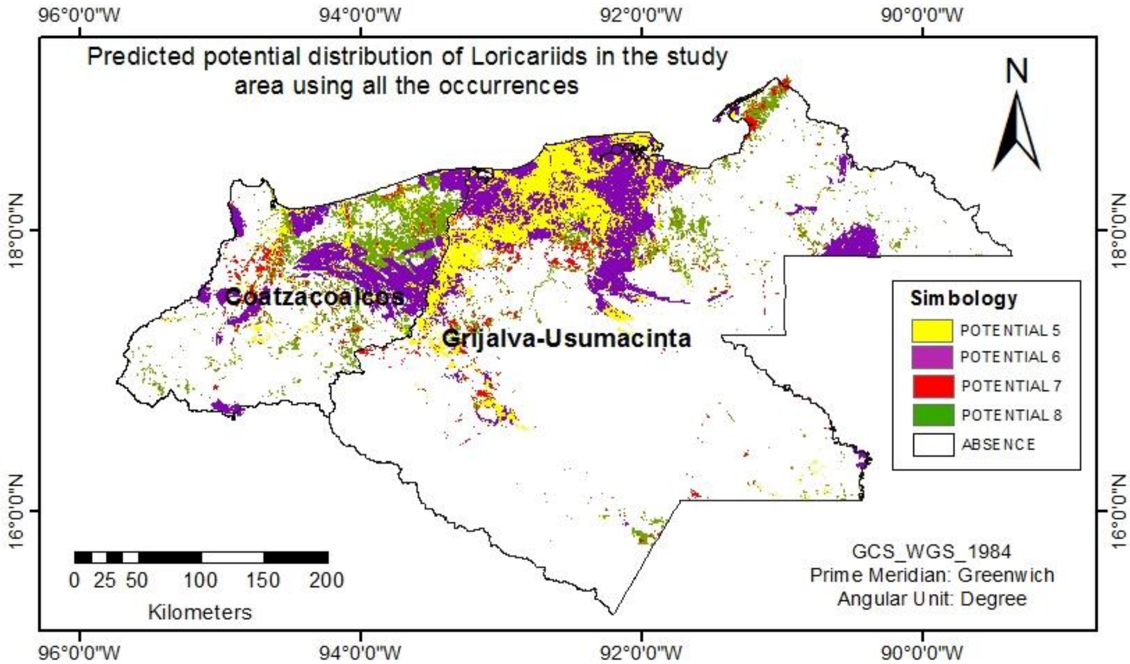

Figure 18. Presence-Absence map of Loricariids comparing four models with different predictors set. The group of occurrences used was OCCURRENCES 2. The prevalence threshold to obtain the binary map was 25.

Pair-wise comparisons between models that share the same set of predictor variables but different number of occurrences were done. Table 10 presents the percentage of common cells that predicted presence of Loricariids when comparing two models. This was done using the raster calculator tool by combining two models and generating a new one showing the cells that both models predicted as a suitable for Loricariids (value=1). The maps obtained are in Appendix 5.

Table 10. Percentage of common area predicted by a combination of pair of models

	Pairwise combination of POTENTIAL models			
	1 & 5	3 & 7	2 & 6	4 & 8
% Common area predicted presence	3.93	3.82	12.50	13.06

7.3 Models using physicochemical variables

7.3.1 Species distribution model

Loricariids predicted distribution models based on physicochemical parameters of the water are depicted in Figure 19. Both models show similar distribution pattern. The higher probability of Loricariids presence is in the Delta of Grijalva-Usumacinta hydrological complex. Sectioned areas along the Grijalva River show medium to high probability of Loricariids presence (probability ≥25). These places include four dams located along the Grijalva River (Peñitas, Malpaso, Chicoasén and Angostura).

Although models appear to be equal, the area predicted with suitable habitat for Loricariids differ. The model based on the presence points OCCURRENCES 2 predicted 38.5% of the area as adequate, while when using OCCURRENCES 1 the model considers that 22.3% of the area has suitable conditions for the establishment of the fish, reported in Table 11 and represented in Figure 20.

Table 11. Matrix summarizing the results of the distribution models generated with physicochemical variables and occurrences of Loricariids out of its native range.

OCCURRENCES 1		**OCCURRENCES 2**	
PHYSICOCHEMICAL 1		PHYSICOCHEMICAL 2	
AUC Trai	***AUC Test***	***AUC Trai***	***AUC Test***
0.92324	0.85036	0.87472	0.78988
Predictor	***Gain***	***Predictor***	***Gain***
Conductivity	22.4	TDS	23.1
DO	21.1	DO	22.3
ORP	19.4	Temp	20.6
Temp	14.7	Altitude	13.9
TDS	10.7	Conductivity	10
% Area predicted as suitable	22.28	**% Area predicted as suitable**	38.53

7.3.2 Validation

The accuracy of the PHYSICOCHEMICAL 1 model is good for the AUC test (AUC Test>0.8) and very good for the AUC training (AUC Test>0.9), while for PHYSICOCHEMICAL 2 decreases for test (AUC~0.79) and for training (AUC>0.8) Table 11.

7.3.3 Predictors

The five variables that contribute more than 10 percent to the total gain for each model are summarized in Table 11. Conductivity, dissolved oxygen and oxide-reduction potential are the predictors than most contribute to the model based on directly obtained occurrences (PHYSICOCHEMICAL 1). The only predictor in common with PHYSICOCHEMICAL 2 according to the three variables with highest gain is dissolved oxygen. This last variable, along with total dissolved solids and temperature represent more than 65% of the total gain for the model PHYSICOCHEMICAL 2.

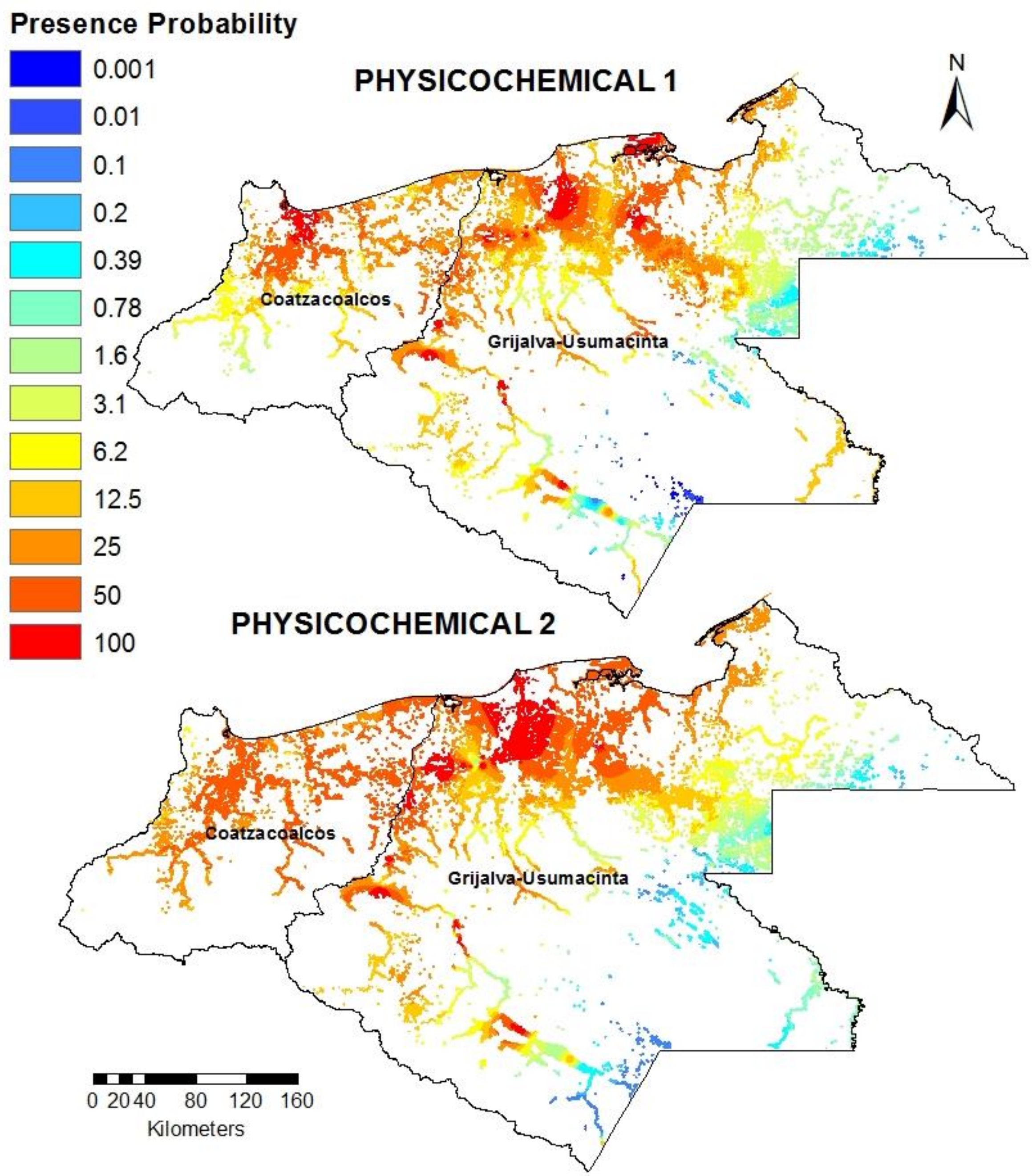

Figure 19. Maxent potential distribution models of Loricariids using physicochemical variables in the Grijalva-Usumacinta hydrological complex

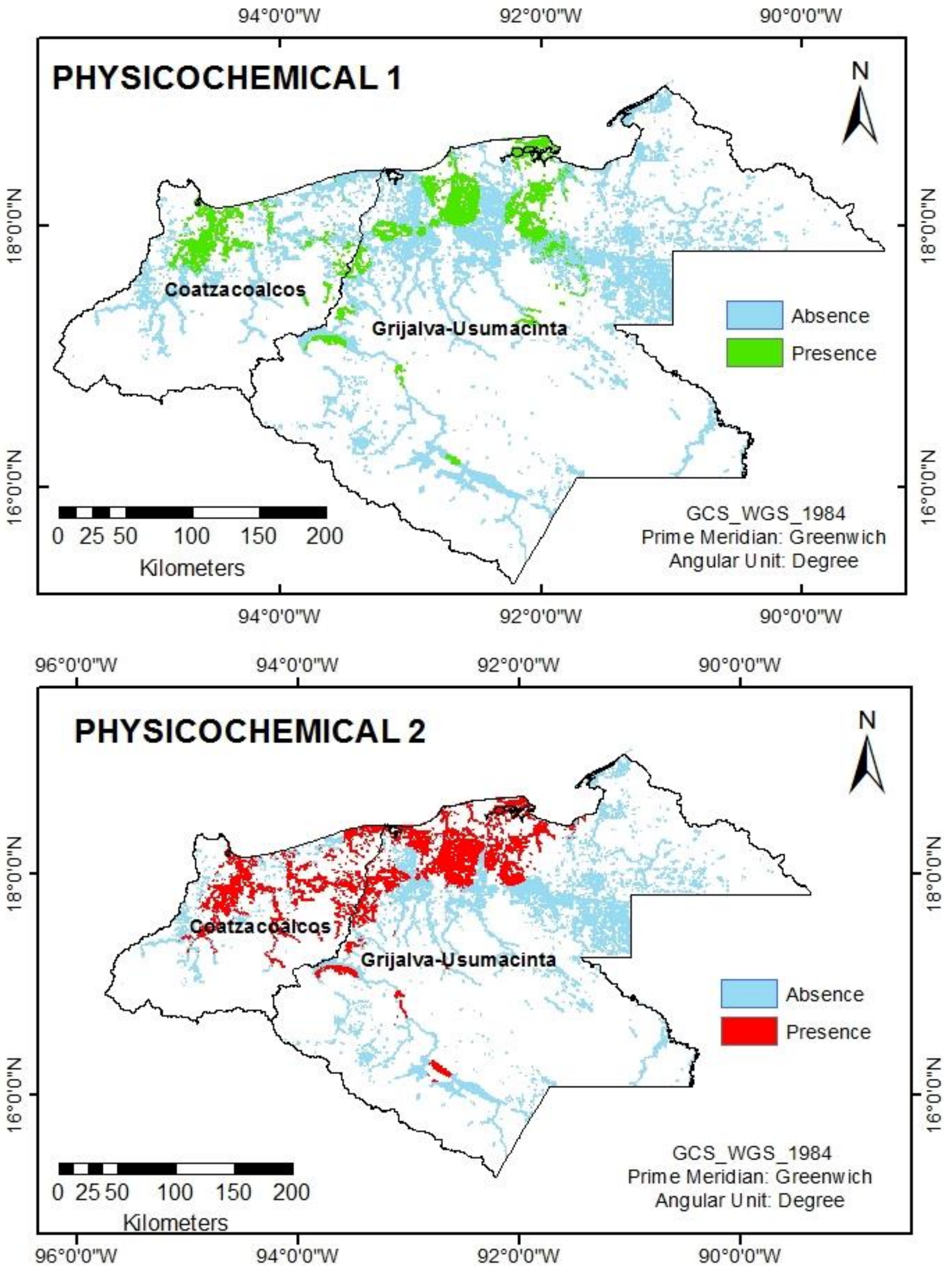

Figure 20. Presence-Absence map of Loricariids comparing two models obtained with physicochemical parameters of water and different occurrences sets. The prevalence threshold to obtain the binary map was 25

7.4 Mathematical model using Hyperniche

A total of 238 models were created by Hyperniche with the input data. The selection of the best fitted models based on the number of predictors significantly reduced the models to only two (Table 12).

Table 12. Hyperniche results. Best fitted models and ranges of variables used as predictors.

Models -

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Model Number	Response Variable	Cutoff	Form	Eval logB	Ave Size	Pred Count	Variable 1	Tolerance	Variable 2	Tolerance
2	Presence	0.000	LM	6.2723	6.5	1	Altitud	28.70000		
232	Presence	0.000	LM	6.4578	5.1	2	Altitud	28.70000	pH	0.61800

The ranges of the variables used as predictors are as follow:

RANGES OF QUANTITATIVE PREDICTORS

	Name	Type	Minimum	Maximum	Range
1	Altitude	Q	0.0000	574.00	574.00
2	pH	Q	6.6700	8.7300	2.0600
3	Temperate	Q	26.100	30.500	4.4000
4	DO	Q	1.8600	10.860	9.0000
5	Conductivity	Q	330.00	520.00	190.00
6	ORP	Q	-12.700	270.00	282.70
7	TDS (ppm)	Q	162.00	268.00	106.00

7.5 Comparison of response curves obtained using physicochemical parameters as predictors.

The results summarized in Table 13 were obtained from the response curves generated by Maxent (Appendix 6) and Hyperniche (Appendix 7) when running the models with physicochemical parameters of the water.

Table 13. Results of response curves of Loricariids to physicochemical parameters of the water obtained with Maxent and Hyperniche.

	PHYSICOCHEMICAL 1	PHYSICOCHEMICAL 2	HYPERNICHE
Temperature (°C)	>28 get stable at 30	>28 get estable at 30	at ~ 26°C prob. Presence > 60%, decreases to 40% at 27°C start to increase and reaches the maximum between 28 and 29°C where start to decrease until 30°C at this temperature the probability of presence is ~ 40%.
pH	high probability between 7.5 and 9.1	Unstable	more than 55% of presence at pH lower than 8.5
Altitude (masl)	Unstable	Unstable	< 200 the probability about 100% . Gap between 200 and 300. Between 300 and 400 probability more than 50%.
ORP (mV)	Unstable	Probability increase at negative values	The more negative the better, at ~ 150 the probability is less than 20%
Dissolved oxygen (mg/L)	Prefers values greater than 7, get stable at 11	Unstable	Probability decreases, as DO increases
Conductivity (µS/cm)	when > 2000 presence > 70%	Unstable	> 450 probability higher than 90%
TDS	> 200	> 200	For all the values in the scale probability >50%. At 180 > 70% and values >230 the probability is higher than 90%

7.6 Fishermen perception

In both field trips, all fishermen interviewed in the state of Tabasco are aware of the existence and presence of Loridariidae fish family in neighboring water bodies. Knowledge of its presence extends southeast of Veracruz (Coatzacoalcos) west of Campeche (Atasta, Palizada and Laguna de Términos) and the northern part of Chiapas (close to Peñitas dam).

Fishermen carrying out their activities in “Malpaso” dam have knowledge of the fish and refer to their presence on the other side of Peñitas Dam curtain. During the first field trip a fisherman identified Loricariids and said that other fisherman have captured it in “Sumidero Canyon” National Park. Unfortunately, it was not possible to confirm the information. A second visit to the area was done to confirm occurrence of fish. In Cahuaré pier, one of the three visited in the area near the "Sumidero Canyon" National Park, a group of fishermen recognized Loricariids and explained that three specimens have been captured, which confirms Loricariids presence in the area. However, in the other two pairs, located less than 5 kilometers from there, Loricariids were not recognized as a result of fishing.

All the people that recognized Loricariids refer to it as "Devil Fish" or "Plecos". In Macuspana and Centla Tabasco it is called "black fish"

In the state of Tabasco, fishermen reported having seen first Loricariids about seven or eight years ago. This estimate includes interviews held out in ten of the seventeen municipalities that make up the state of Tabasco. Fishermen do not know from where Loricariids came, but they mentioned that it could have been introduced by the Federal Commision of Electricity (CFE) to clean the tubs of the hydroelectric system in the dams.

In the area of Coatzacoalcos, Veracruz, and Atasta, Campeche, the first sightings of Loricariids date about three years ago, while in the National Park "Sumidero Canyon" they were found a year and half ago.

Most of the interviewed fishermen who had knowledge about Loricariids in the area where they fish said that "devil fish eats other fish eggs". According to that, the quantity of native fish (common names: tenguayaca, castarrica, macabil, bagre, lobina, mojarra phichincha) and commercial fish like tilapia have decreased. Other negative impacts identified by fishermen are gillnets damage, increment of the labor force, more labor hours to obtain minimum amount of fish. This has led to membership decline in some fishing cooperatives, thus unemployment rises.

Proportion of actual fishery versus fishery before Loricariids (Table 14):

Table 14. Impacts of Loricariids identified by fishermen. Information obtained by direct interview to presidents of three different fishing cooperatives.

Place	Number of fishermen	Fishery before Loricariids	Actual fishery (with Loricariids)
Pair "Pantanos de Centla 2". Centla, Tabasco.	38 actual	20-24 kg/6 working hours per day	4-5 kg/about 10 working hours per day
Fishing Cooperative "Estrecho de la Herradura". Rómulo Garza, Chiapas. Near to Peñitas dam.	79 six years ago, 38 actual	23 kg/6 working hours per day (8kg in three hours at mornings + 15 kg in three hours at afternoons)	3-4 kg/ about 8 working hours per day
Fishing Cooperative "Nandambua" Osumacinta, Chiapas belonging to National Park "Sumidero Canyon"	52 actual	15-16 kg/6 working hours per day	4-5 kg/about 8 working hours per day

What do fishermen do when they find "Devil fish"? Do they have considered eating it? They put them out and throw them on the river banks, which causes "bad smells". Only one family was known to consume the Loricariids in the state of Tabasco, they expressed that it takes too much effort to kill the fish (due to the "armor") and to obtain only a little amount of meat.

Although most fishermen do not give the devil fish any use, some of them have heard of projects to produce flour for cattle with the fish meat.

8 DISCUSSION

Different models were developed with the aim of finding the combination of predictors that better represents the potential distribution of Loricariids. To achieve this, ten different models were performed with Maxent varying the amount and type of variable (continuous and categorical), and the quality and number of occurrences used.

Being Loricariids an invasive species the first models done were based on occurrences of the native range of distribution.

8.1 Methods

The predictors used to model in the terrestrial area were not difficult to obtain. All of them were already available online on different sources (CONABIO, 2008; Hijmans *et al*., 2005; SEMARNAP, 1998) and at different resolutions. The existence and availability of global layers greatly facilitate the modeling of terrestrial species distribution, since the layers only need to be at the same projection and geographical extend. The case was not the same when obtaining the primary occurrence data of Loricariids occurrences and the sampling of aquatic parameters; it was not an easy task. The sampling points were supposed to be measured systematically according to the altitudinal gradient but that was no possible due to inaccessibility to the river. In the upper part of the Grijalva River, during the second field work, the River was almost always visible from the roadway; but it was located in the valley, while the roadway is on the mountains. In the places that were accessible other difficulties arose. At some locations, turbidity of the water did not allow a direct observation in the river, leading to uncertainty in the Loricariids occurrences. Fishermen were not located every time along the river, so to interview them was also a challenge. To monitor the presence of nests in river banks along the river was also not possible because a boat was needed, so it was limited to punctual locations. An exhaustive monitoring of the whole study area is needed to test out the absence points reported as true absence. The information obtained regarding the presence of Loricariids is reliable because it was confirmed by direct observation of the fish species and by fishermen identification. In the locations were Loricariids have been since at least six years, it was really easy to identify their presence by watching a black spot moving in the water (they are often found in groups) followed by the aquatic duck “Cormorán” (a Loricariid predator observed during field work). In Tabasco State, 100 percent of the fishermen were able to fish a Loricariid and show it. However, in “Sumidero Canyon” National Park, it was not possible to fish a Loricariid. Fishermen argued that there are not too much in the area since the first sight was about one and a half year ago. This observation is related with the dispersal and establishment rate. And it seems, according to the interviews, that Loricariid establishment and consequent invasion take less than five years. Detailed studies about dispersal ability and establishment are needed to consider options for eradication and prevention.

The measurement of physicochemical parameters of the water in the River was also limited by the availability and optimal performance of the multiparametric probes. In the first field work phase two multiparametric probes were used, leading to six physicochemical parameters measured. Unfortunately during the second field work only one of those was working properly, reducing the physicochemical parameters measured in the upper part of the Grijalva River to four.

Considering data availability the first models were based on terrestrial predictors as the majority of invasive species studies are carried out, also for aquatic species (Barbosa *et al*., 2012). In order to contribute to fill the gap in species distribution models in aquatic environment, the physicochemical parameters were measured and used to obtain a continuous predictor layer.

8.2 Potential distribution based on native and invaded ranges

According to model NATIVE 1, only about eight percent of the territory in the study area has climate matching suitable for Loricariids. However the result corresponds to less than half of the area predicted by the models POTENTIAL 2 & 6 based on occurrences of the invaded area. This result may have two reasons. The first, related to the adaptive capacity of the Loricariids to new environmental conditions meaning that Loricariids have not kept their native climatic niche in the new area, but they have expanded it, as it has been proved for other invasive species (Mandle *et al*., 2010). The second, multicollinearity between most of the bioclim variables interferes with the prediction. The model NATIVE 2 made only with selected not highly related climatic variables and the altitude, predicts that more than 50% of the territory have suitable environmental conditions for Loricariids establishment in contrast with NATIVE 1 that predicts less than 10% of the territory as suitable. According to that, the use of high correlated variables as predictors has a significant effect reducing the predictive ability of the model.

Unfortunately NATIVE 2 could not be directly compared with any of the POTENTIAL models, because the set of predictors used are different. Instead of a direct comparison, it can be observed that any of the POTENTIAL models predicts more than nineteen percent of the area as suitable for Loricariids (Table 9). It is important to consider that all POTENTIAL models are based on actual occurrences in the invaded range and does not mean that places where Loricariids is absent are not suitable. Biotic interactions should be taken into account to determine the dispersal rate of the species, competitors and the time that Loricariids need to establish (Austin, 2002).

Models POTENTIAL 4 & 8 predict high presence probability regions not considered in the model NATIVE 2. Actually, some places where Plecos were already found, like "Sumidero Canyon" National park, are not predicted as presence using native occurrence points. This result can be supported by the idea that the position and shape of the fundamental ecological niche vary according to the invasion process (Soberón and Peterson, 2011). Thus, the species distribution model of Loricariids should not be based only on NATIVE predictions, because for invasive species mismatching or "shifts" between the environmental conditions of the native range and the novel places can be expected. (Soberón and Peterson, 2011)

The prediction capacity of the models was evaluated not only for the degree of correlation between variables but also for the type of variable used.

Predicted presence areas for Loricariids in models POTENTIAL 1 & 3 are very close, in both cases less than five percent (Table 9). In comparison, models POTENTIAL 2 & 6 predict more than 15 percent of the area as suitable for Loricariids (Table 9). The clustering and aggregation effects of using categorical variables as predictors are shown in the binary maps (Appendix 5) between POTENTIAL 1 & 3 and POTENTIAL 2 & 6, as well a more spread predicted presence distribution is observed for models POTENTIAL 3 & 7 and POTENTIAL 4 & 8. The models showing better prediction are the ones done only with continuous variables as predictors considering the predicted area obtained.

Related to the number and quality of occurrences, tendencies are reversed. If the number of occurrences increases, the percentage of predicted area increase for models using categorical variables. Contrary to the models that use only continuous variables, which predict area decreases. The approximation made to consider the occurrences reported in newspapers does not have the same quality as the directly obtained occurrences and did not have the expected improvement in prediction capacity. Considering only the predicted area, there are not strong differences between the models using OCCURRENCES 1 or OCCURRENCES 2. According to percentage of area predicted as suitable models POTENTIAL 2 & POTENTIAL 4 are the best. To decide which of those have most suitable set of predictors, a predictor analysis was done.

8.3 Predictor analysis

All the models had good to very good accuracy, according to the AUC for test and training (Table 9) and were used to obtain tendencies regarding the weight each variable has in the model.

8.3.1 Continuous variables

The two models based on bioclim variables (POTENTIAL 2 & 6) predict as important a set of four variables derived from temperature. The only two variables common between them are mean temperature of warmest quarter and mean temperature of driest quarter. They are not consistent on assigning neither similar predictors nor closer gain values for each of them. This predictor selection with only general tendency to temperatures could be due to higher correlation between variables (Phillips *et al*., 2006)

Interesting results are obtained from model POTENTIAL 4 which assigns the highest gain to NDVI (Table 9). This Index is a measure of how "healthy" is the vegetation. The response curve for NDVI is presented in Figure 21. The negative values are normally water, but the layer used has "no data" for water bodies and that is why the scale starts near to zero. High relative probability of Loricariids presence ranges from zero to ~0.4. And it decreases as the NDVI gets closer to 1. This behavior can be interpreted as the preference of the Loricariids to be present in water bodies that are adjacent to areas moderately or highly disturbed. In all the other models NDVI was also rated within the three best predictors (gain>15)

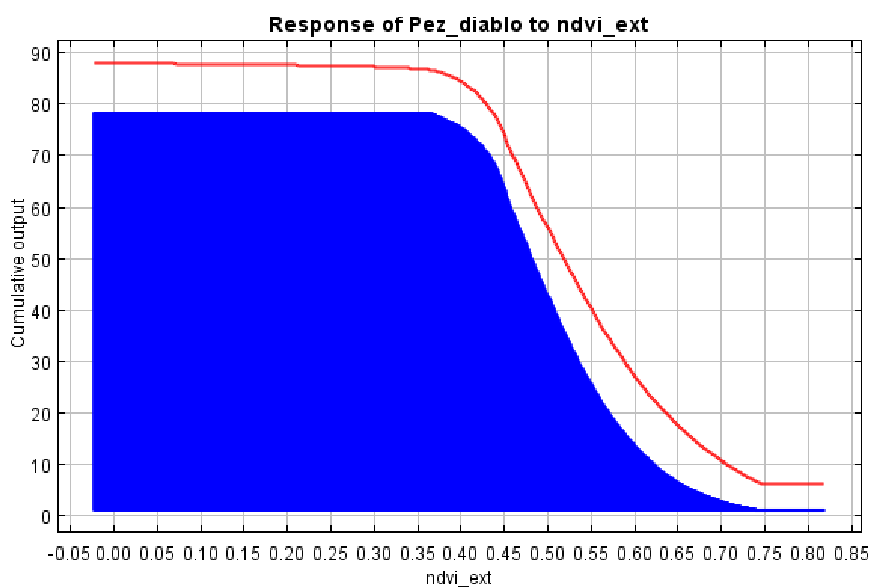

Figure 21. Response curve for Loricariids to Normalized Differential Vegetation Index (NDVI) for model POTENTIAL 4. The curve show the mean response of the 5 replicate Maxent runs (red) and the mean +/- one standard deviation (blue)

The presence of Loricariids in model POTENTIAL 4 is determined also by the accumulation of flow in certain areas. This variable is the only continuous layer used as water presence indicative in the selected set of no highly correlated variables. The altitude contributes about 19% for the total prediction of the model. The response curve shows the higher presence probability of Loricariids at negative values, corresponding to areas located in Tabasco floodplain and Grijalva-Usumacinta Delta. The predicted relative presence of Loricariids is about 20% at 1000 meters above sea level. This result differ from the altitude reported in literature, which is for a native range up to 3000 masl (Matthews, 1998). The result can be explained as if Loricariids have not yet reach the limit of its distribution; this could be due to biotic interactions, dispersal time or to the presence of physical barriers like the four dams located along the Grijalva River.

Isothermality (iso) also contributes highly to the model. The highest presence probability of Loricariids is about 0.6. This variable is a measure of temperature evenness within an area (Mischler *et al.*, 2012)

The last variable is the precipitation of coldest quarter (pcf), with a smaller gain that the other predictors explain that the relative probability of Loricariids is more than 50% for 400mm of precipitation.

8.3.2 Categorical variables

A general analysis of the categorical variables was done due to the consistent results of the models that use them as predictor variables.

The sub-categories predicted as more important for the models are summarized in the Table 15.

Table 15. Subcategories depicted as the more important for at least three of the four models compared.

	Land use and vegetation (veget)		**Soil type (suelos)**		**Drainage basin (areaest)**	
	ID	Description	ID	Description	ID	Description
Categories that had greater values in at least 3 of the 4 models compared (POTENTIAL 1, 3, 5 & 7)	0	Urban area	3	Litosol	7	Río Grijalva-Tuxtla Gutiérrez
	1	Agriculture	11	Cambisol	8	Río Grijalva-Villahermosa
	27	Cultivated pasture	16	Gleysol	3	Río Usumacinta
	31	Forest-induced grassland	1	Solonchak	9	Río Grijalva-La Concordia

Predicted presence of Loricariids is highly related to urban areas, agriculture, cultivated pasture and forest induced grassland. Land use and vegetation type predictor layers match with the interpretation that Loricariids inhabit water bodies near to disturbed areas.

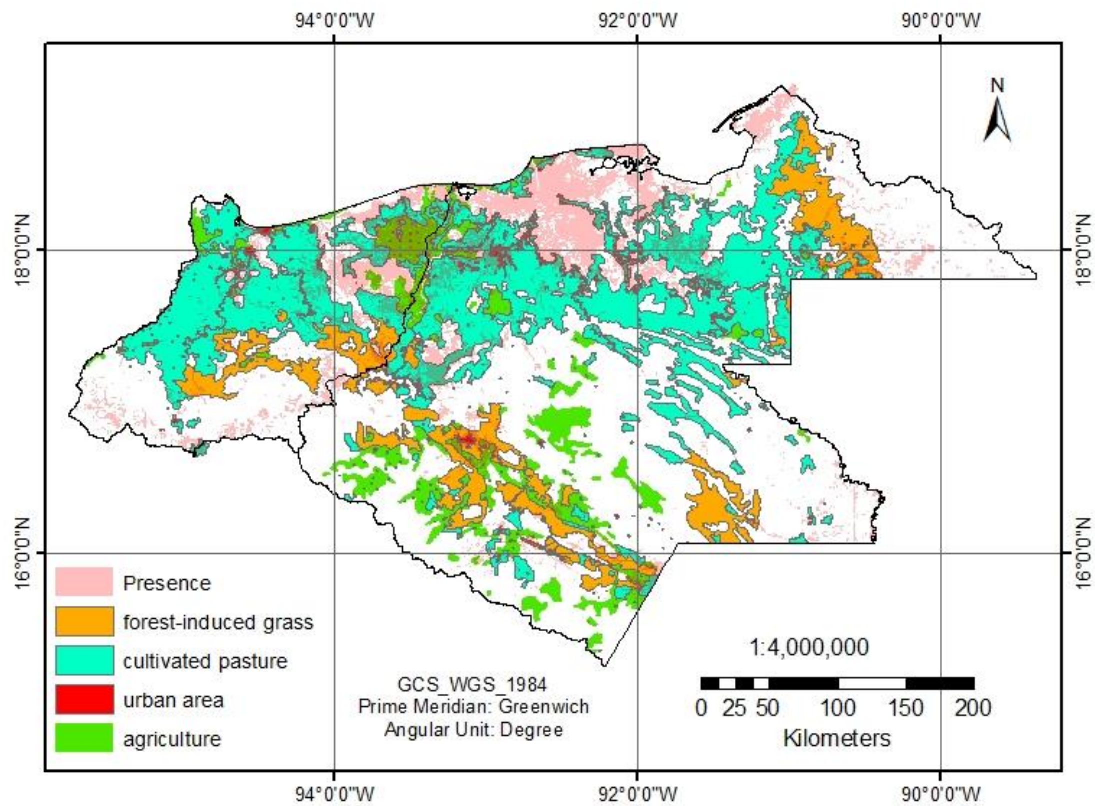

Figure 22. Presence of Loricariids predicted by model POTENTIAL 4 according to land use and vegetation. Shapefile retrieved of CONABIO (2008).

The soil type that determine Loricariids presence according to the models are Gleysol, Solonchak and Cambisol. The importance of this information is related with nesting habits. Loricariids need soils with medium to fine texture to be able to cave in the shorelines. The results are consistent according to Greene and Lee (2009), who found that Loricariids prefer clay soils that are conductive to burrowing for laying eggs.

The basins that are threatened by Loricariids invasion are Rio Grijalva-Tuxtla Gutierrez, Río Grijalva-Villahermosa, Río Usumacinta and Río Grijalva-La Concordia. In the first three basins Loricariids have been already found. Río Grijalva-Villahermosa comprises the area from Peñitas Dam to Villahermosa and ends in the Delta of Grijalva-Usumacinta hydrological complex. River Usumacinta basin also ends in the Delta but comprises the eastern part of Tabasco and western part of Campeche. In the basin Río Grijalva-Tuxtla Gutiérrez is located "Sumidero Canyon" National Park. Río Grijalva – La Concordia is a basin that includes the upper part of the Grijalva River, after Chicoasén Dam and the high risk of presence can be used for focusing efforts on invasion prevention. The results also represent the sampling efforts in the study zone, giving a better prediction for basins complete sampled.

8.4 Potential distribution based on physicochemical parameters

Loricariids distribution models obtained with Maxent using physicochemical variables show higher effects to the different set of occurrences used. The percentage of area predicted was about 16% more in PHYSICOCHEMICAL 2 than PHYSICOCHEMICAL 1. While interpreting the results it is necessary to evaluate the accuracy of the models. The accuracy of the model PHYSICOCHEMICAL 2 clearly decreased to an AUC mean value for test less than 0.8. Although with this adjustment the model is still usable, it demonstrates that a good model fit needs reliable data as input as explained by Chefaoui and Lobo (2008). The gain assigned for the parameters also differ, this is also related to the correlation between variables, for example the indirect correlation between conductivity and TDS causes that in the model PHYSICOCHEMICAL 1 the conductivity was the parameter with most gain, while in PHYSICOCHEMICAL 2 was the parameter that less contributed.

8.4.1 Suitable habitat

The response curves obtained through Maxent and Hyperniche share general tendencies that define the preferred ranges for Loricariids.

Table 13 shows that Loricariids inhabit waters with temperatures ranging from 26 to 30°C , can survive either to slightly acidic waters (pH=6.8) to hard waters (pH=8.5), the maximum spread has been in altitudes below 200 masl but having more than 50% of presence probability between 300 and 400 masl. Loricariids are at most present in low quality water bodies having negative ORP values, low dissolved oxygen and high values of conductivity and total dissolved solids. These conditions agree perfectly with the reported warm temperatures and degraded systems conditions required for Loricariids in Florida (Greene and Lee, 2009) and with lower altitude, high conductivity sites related to *Pterygoplichtys disjunctivus* in Amacuzac River, Mexico (Trujillo-Jiménez *et al*., 2009). The results have slightly differences compared with the conditions reported by Mendoza Alfaro *et al* (2009b) which consider a preferred thermal range for Loricariids between 20-28°C and a waters with pH from 5.5 to 8.0.

The suitable ranges obtained by different authors are result of the environment present in the study area and does not imply that those ranges match with the physiological limit of the species.

The method implemented to create the environmental layers of the physicochemical parameters of the water worked, but the product layers were restricted to less than 40 sampling points, causing that some response curves obtained with Maxent could not be interpreted. However, the results provided a general overview of the preferred conditions for Loricariids. The environmental niche model created with Hyperniche complemented the gaps in the response curves obtained by Maxent.

8.4.2 Set of predictors related to ecological niche

A relevant set of predictors concerning the ecological niche of Loricariids was obtained. The response curve of Loricariids presence against NDVI denotes Loricariids preferences for water bodies near to perturbed areas. The types of perturbation could be identified by using the categorical variables land use and vegetation. That variable gave as result that urban areas, agriculture and induced pasture were the categories more related with Loricariids presence. A link between the terrestrial model and the model based on physicochemical variables can be established considering the ecological niche of Loricariids. They clearly prefer in the new range of distribution, waters with low oxygen content, high conductivity, high temperatures and negative values of ORP. The combination of those physicochemical parameters in the water is result of human presence. The higher conductivity and total dissolved solids values were found in urban areas next to the urban drainage (Villahermosa) and petrochemical complexes ("Pajaritos" unit in Coatzacoalcos). Low oxygen content and negative values of ORP are indicative of polluted waters and eutrophic water bodies related to agricultural practices, for example the use of fertilizers (FAO, 1996). The excess of nutrients mainly based on phosphates and nitrates from fertilizers, causes an algae boom and consequent oxygen depletion in the water body, leading a perfect environment for Loricariids establishment.

Altitude and precipitation of the coldest quarter are also important variables, because the first is related with the water temperature and the second can modify it. Although in this study the water temperature was not a barrier for Loricariids, the ecological niche depends on it as it has been demonstrated that low water temperatures (8.8-11.1°C) have been the only physicochemical parameter that act as a physiological barrier for Loricariids establishment and invasion (Greene and Lee, 2009; Mendoza Alfaro *et al*., 2009b).

8.5 Impacts, perceptions, opportunities and challenges

The knowledge about the "Devil Fish" has increased in recent years because of the perception of species' impact. Realization of these impacts is depending on the time for adaptation, establishment and invasion of the species. In the area of Tabasco all the people interviewed could answer the question regarding Loricariids. In contrast from the fishermen from the central part of Chiapas, only a small group could identify and speak about them. The impacts reported by fishermen in the study area (Table 14) are in concordance with the impacts obtained from literature comprising economic losses, decline of tilapia population, gillnet damages, unemployment and increase in the labor force (Mendoza Alfaro *et al*., 2009a; Stabridis Arana *et al*., 2009). Although 25 interviews were held, only the results of the interviews in the fishing cooperatives are summarized in the Table 14. Those results are based on local registries of the cooperatives, leading to an objective approach. The increase in labor hours, due to decrease on fish capture share a relation with the estimated time that Loricariids have been found in the areas. Loricariids estimated presence of more than five years in "Pantanos de Centla" led a decrease of about 75% of fishery and, at least 4 hours more of labor. In "Estrecho de la Herradura" fishing cooperative, unemployment have increased significantly (about half of the original number of fishermen). The tendency continues in Osumacinta, with a reduction of one third of the original fishery and two hours of extra labor contrasting with about two years of Loricariids first occurrence. However, a further socio-economic analysis related with dispersal and establishment rate is needed. This information will be valuable to determine the magnitude of the impacts and to see which fishermen (small or large-scale) are most threatened by Loricariids invasion.

The real cause of introduction of Loricariids to the Grijalva River basin is still unknown. The "popular knowledge" that CFE intentionally release them to keep tubs "clean" it is not a far possibility considering that in Caracoles Reservoir (upstream from Infiernillo Reservoir) Loricariids were used to control and clean algae from the water body and it spread since then (Mendoza Alfaro *et al*., 2009a). Additionally the aquarium farms and aquarist fish trade contributed to increase the population with the release of at least six different species in the Río Balsas basin (Mendoza Alfaro *et al*., 2009a).

In the study area, more specific in the state of Tabasco it can be supposed that severe flood events (e.g. in 2007) have contributed to the dispersal of the fish, taking into account that natural events, like hurricans and thypoons have been considered to facilitate the entry in novel water in other parts of the world (Mendoza Alfaro *et al*., 2009b).

The absence of natural predators is the new areas is an important factor to consider, however, during the field work it has been observed and confirmed by fishermen that the aquatic duck named "cormorán" (*Phalacrocorax*) consume Loricariids up to a size of approximately 15 centimeters or smaller. Considering that, the dispersion of Loricariids through birds should not be discarded.

9 MANAGEMENT

An eradication plan for Loricariids in places were populations are already established seems difficult (Trujillo-Jiménez *et al*., 2009). Nevertheless, some strategies could be implemented to control the population, diminish the ecological impacts for native species and ecosystems and compensate the socio-economic negative effect. Actions to prevent the proliferation in areas that have suitable conditions for Loricariids establishment are necessary (Figure 23).

9.1 Efforts

Loricariids is consumed by humans in their native geographical range of distribution (Mendoza Alfaro *et al*., 2009b). However, in the study area it has been rejected by most of the people that depend on fishery due to the appearance and difficulties to obtain the meat. Isolated efforts have been done in the state of Tabasco through scholar projects in the municipalities of Macuspana, Balancán and Tenosique.

The undergraduate students from CONALEP School have proposed human consumption of Loricariids by generating diverse meals options. Another group has created belts, shoes and sandals taking advantage of the "Devil fish" hard exoskeleton (oral presentation in the regional fest in Macuspana municipality). In addition, formal research to transform Loricariids in a profitable product has been done. Cano Salgado (2011) has elaborated Loricariids fish flour to feed tilapias with good grow rates.

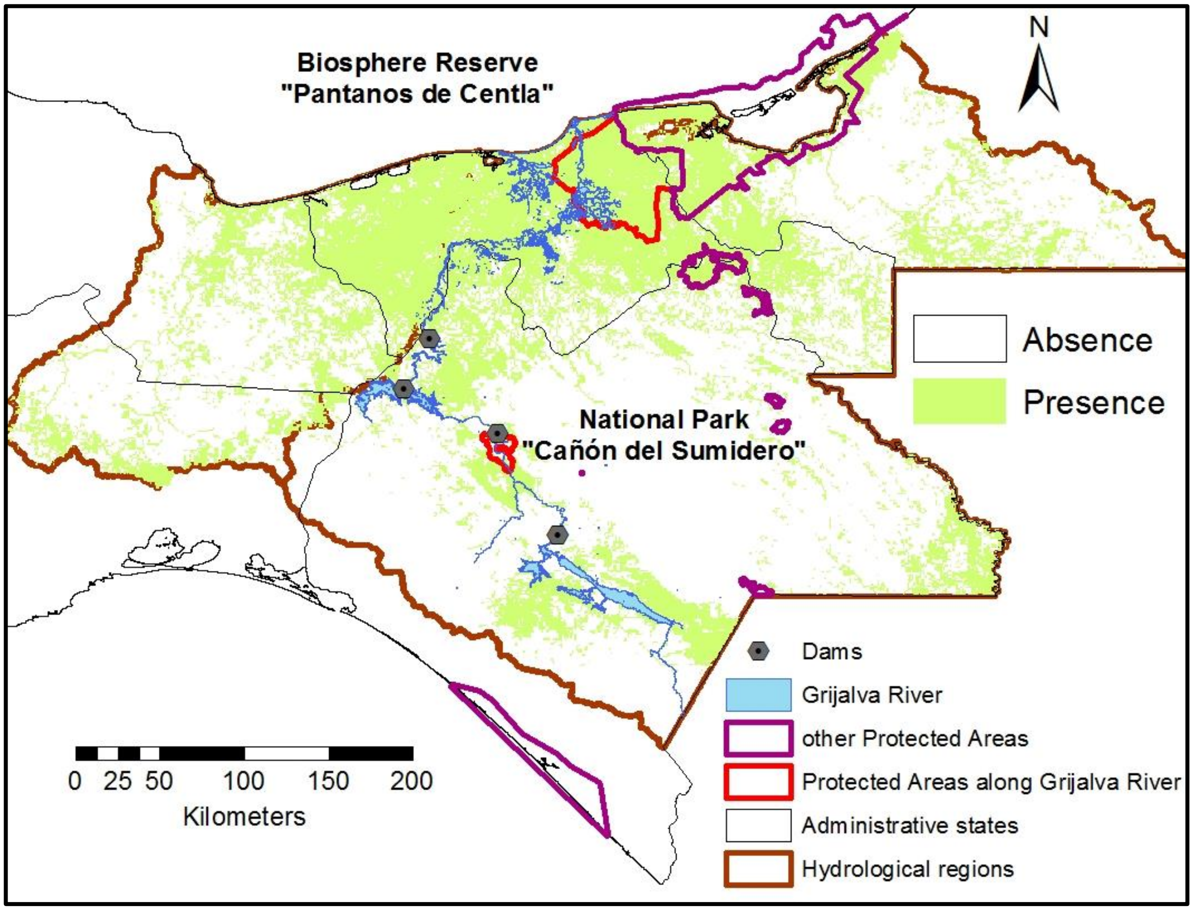

Figure 23. Map representing suitable habitat for Loricariids obtained by Maxent (POTENTIAL 4). In red: protected areas along Grijalva River. In purple: other protected areas.

In Michoacan state, an eradication plan for Loricariids has been implemented, considering not only the capture but also the industrialization of devil fish. As a support for industrialization purposes, the percentage of meat that could be consumed, as well protein contain of the meat was calculated through bromatologic analysis, leading as a result that 19% of the weight of the organism can be used for human consumption with high proportion of protein and thus used to enrich formulations diets for animals (Escalera-Gallardo *et al*., 2006).

Mendoza Alfaro *et al*. (2009a) suggest further investigation to analyze if human or animal consumption of Loricariids is safe, taking into account other authors that have reported the capacity of Loricariids to accumulate heavy metals.

All the actions mentioned are related with eradication based on grown fish and obtaining economic benefit after processing the fish. Egg harvesting is a direct option that have been implemented by fish farmers, consisting on paying 5 usd for Loricariid egg masses instead of raising them, an income of about 500 to 750 usd per day have been estimated (Greene and Lee, 2009).

At a national level, Stabridis Arana *et al*. (2009) reported that the National Council of Science and Technology (Consejo Nacional de Ciencia y Tecnología CONACYT) is financing a project to produce surimi from Loricariids.

Many actions and proposals to eradicate or control Loricariids have been implemented. Unfortunately, rather than develop an integral and continuous plan, efforts have been constraint to individual projects. There are not preventive actions recommended at national level to protect places identified as suitable for invasions.

Lack of information in places where the species is present but not yet established contributes to proliferation of the species. Information generated by every project should include an educative and informative program. The basin Río Grijalva – La Concordia was identified as a zone with high risk for Loricariids establishment. Preventive actions to protect the upper part of the Grijalva River are necessary. Policies regarding fish trade should constraint the introduction and possession of Loricariids. A continuous management plan for invasive species should be developed and take advantage of novel technologies, for example the implementation of a real-time early detection system for Loricariids. This could be achieved by including fishermen as everyday monitors using cellphone technology. During the interviews fishermen mentioned that they are willing to work together to control and find alternatives for fishery in the region.

Of course, the main constraint to implement such a big plan is the investment, but with a cost-benefit analysis realized on time, the right decisions regarding invasive species can be taken.

Being the Grijalva River a transboundary river, collaboration between neighboring countries should be considered to establish eradication and prevention actions.

10 CONCLUSION

To predict species geographic distribution of invasive species remains a challenge. The comparison between the different models obtained showed that multicollinearity between variables used as predictors, the number and quality of occurrences and the type of predictors used affect the predictive capacity of the model.

Maxent performed well for all the models generated. The potential distribution of Loricariids obtained with native occurrences (NATIVE 2) predicted a greater area than the models using occurrences of the non-native range, however a “shift” in the predictions was observed. To clarify the result, an inclusion of biotic interactions to determine the physiological limits of Loricariids in the new range should be done (Rödder *et al*., 2009)

The best model was POTENTIAL 4 considering the area predicted as suitable and based only on selected continuous predictors using directly obtained set of occurrences. The use of categorical variables as predictors do aggregate or confine the distribution to specific areas, but the gain assigned to the sub-classes gives valuable information. Using model comparisons a representative set of predictors for Loricariids habitat was obtained.

The inclusion of models based on physicochemical parameters of the water gave information related to the physiological tolerances of the fish according to the actual distribution. To model in aquatic environments using direct variables (pH, temperature) required exhaustive field work and a systematized method of sampling. Difficulties arise for measuring in the river at a defined location where the access is restricted by geographical barriers.

Loricariids species distribution was obtained and the results based on indirect environmental variables match with the interpretation of direct parameters.

The areas already invaded and in risk of invasion were identified to be used for a prevention / eradication plan. Actions implemented should not be isolated, but integral and continuous including policies, prevention and education.

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Appendix 1. Geo-referenced inventory of Loricariids ocurrences

Basin	Longitude	Latitude	Ocurrence	Altitude (m)	pH	Temperature (°C)	Dissolved Oxygen (mg/L)	ORP (mV)	TDS (ppm)	Conductivity (microS/cm)	Source
G-U	-93.5938876	17.1285736	0	176	8.04	30.5	8.86	113.5	172	344	*
G-U	-92.6618918	16.2148601	0	526	8.15	29.8	7.09	114.9	189	384	*
G-U	-93.036684	16.7451504	1	392	7.76	26.1	5.68	270	222	427	*
G-U	-93.0574937	16.7771825	1	389	8.03	26.2	6.31	107	244	464	*
G-U	-93.0700374	16.7965688	1	368	8.01	26.5	6.5	92.1	268	520	*
G-U	-93.1076748	16.8390844	1	291	7.91	26.8	4.87	84.6	212	415	*
G-U	-93.0932775	16.9002989	1	388	8.73	27.9	10.86	84.5	190	379	*
G-U	-93.0958668	16.933003	1	391	8.72	27.9	10.55	81.7	189	378	*
G-U	-93.1061948	16.9619608	0	204	7.58	27	4.29	69.3	202	391	*
G-U	-93.1073691	16.9623127	0	205	7.79	26.9	4.28	59.6	201	391	*
G-U	-93.5816798	17.2021686	1	84	7.66	28.1	3.82	78.8	183	360	*
G-U	-93.5813241	17.2026758	1	85	7.83	28.1	3.79	57.5	182	360	*
G-U	-93.5524201	17.3465488	1	88	7.76	30	6.16	73.5	176	363	*
G-U	-92.8140589	16.5483001	0	396	7.63	26.1	4.47	91	203	400	*
G-U	-92.9964276	16.6295342	0	399	7.94	27.4	6.81	18.2	167	330	*
G-U	-93.4811539	17.4689481	1	44	7.91	28.3	5.52	31.6	180	363	*
G-U	-93.4021195	17.6283343	1	44	7.9	28.5	6.31	25.9	178	360	*
G-U	-93.4203165	17.7273971	1	39	7.98	28.9	6.64	31	176	359	*
G-U	-92.9959011	17.9689022	1	11	8.04	28.6	6.85	25.6	162	345	*
G-U	-93.0405458	17.970317	1	17	8.04	28.6	6.96	23.4	173	350	*
G-U	-92.9214064	17.9814681	1	12	6.67	28.6	1.86	35.2	236	491	*
G-U	-92.918921	18.0255033	1	10	7.99	29.5	6.39	4.3	174	359	*
G-U	-92.8351282	18.0180746	1	10	7.64	29.2	4.94	-12.7	173	351	*
G-U	-93.1824723	17.9634113	1	17	8.06	29.1	7.52	-4.2	175	359	*
G-U	-92.6506693	18.5075585	1	2	7.61	28.4	4.82	13.8	181	373	*
G-U	-92.6489067	18.4053256	1	7	7.57	29	4.54	11.4	191	399	*
G-U	-92.6663702	18.2746738	1	0	7.59	29.5	4.43	20.4	209	431	*
G-U	-92.6942649	18.2127899	1	2	7.67	29.3	4.47	27.1	176	362	*
G-U	-92.7083371	18.1448704	1	5	7.67	29.5	4.4	15.5	174	357	*
G-U	-92.9372888	17.993893	0	1986	7.75	18.2	3.11	nd	nd	350	*
G-U	-92.178987	15.3914917	0	1064	8.38	21.8	7.17	nd	nd	242	*
G-U	-92.1126852	15.4364821	0	865	8.88	22.6	8.05	nd	nd	268	*
G-U	-92.1578577	15.593131	0	680	8.68	24.9	8.31	nd	nd	274	*
G-U	-92.2429505	15.9426438	0	532	8.44	27.2	8.63	nd	nd	441	*
Coa	-94.4534684	18.1062048	1	18	8.24	24.8	7.04	nd	nd	1644	*
G-U	-91.9615693	17.4478846	1	30	8.27	22	7.43	nd	nd	432	*
G-U	-92.1332504	18.0891754	1	19	8.24	25.4	7.66	nd	nd	661	*

G-U	-92.1078079	18.6186795	1	3	8.3	24.2	6.59	nd	nd	1971	*
G-U	-92.021283	18.260072	1	nd	nd	nd	nd	nd	nd	nd	RG
G-U	-91.900978	18.342368	1	nd	nd	nd	nd	nd	nd	nd	RG

Basin	***Longitude***	***Latitude***	***Ocurrence***	***Altitude***	***pH***	***Temperature (C)***	***Dissolved Oxygen (mg/L)***	***ORP (mV)***	***TDS (ppm)***	***Conductivity (microS/cm)***	***Source***
G-U	-91.861367	18.377273	1	nd	nd	nd	nd	nd	nd	nd	RG
G-U	-94.087867	17.909701	1	nd	nd	nd	nd	nd	nd	nd	RG
Coa	-94.543886	17.977556	1	nd	nd	nd	nd	nd	nd	nd	RG
Coa	-94.438077	17.888847	1	nd	nd	nd	nd	nd	nd	nd	RG
Coa	-94.524185	18.109236	1	nd	nd	nd	nd	nd	nd	nd	RG
G-U	-92.331111	16.01	0	574	8.62	29.44	9.95	342	25.6	171	RG
G-U	-92.4225	16.0891667	0	549	8.54	29.49	6.96	346	35.3	173	RG
G-U	-92.543056	16.105	0	526	8.55	29.62	6.76	344	66.3	172	RG
G-U	-92.7075	16.2316667	0	514	8.63	29.97	6.93	340	136.1	170	RG
G-U	-92.5944444	18.3738889	1	nd	8.23	28.7	6.74	nd	nd	nd	Capps
G-U	-92.5838889	18.3763889	1	nd	8.16	29	6.65	nd	nd	nd	Capps
G-U	-91.8430556	18.3583333	1	nd	8.9	30.1	8	nd	nd	nd	Capps
G-U	-92.645	18.4927778	1	nd	8.24	31	6.6	nd	nd	nd	Capps
G-U	-92.6908333	18.4811111	1	nd	8.24	29.3	6.79	nd	nd	nd	Capps
G-U	-92.6688889	18.5461111	1	nd	6.86	28.2	4.29	nd	nd	nd	Capps
G-U	-92.6744444	18.5572222	1	nd	7.1	29.1	3.07	nd	nd	nd	Capps
G-U	-92.6130556	18.3877778	1	nd	7.41	27.2	4.28	nd	nd	nd	Capps
G-U	-92.6941667	18.5977778	1	nd	7	29.1	3.61	nd	nd	nd	Capps
G-U	-91.9715028	17.4883472	1	nd	nd	nd	nd	nd	nd	nd	Capps
G-U	-92.6344528	18.5239889	1	nd	nd	nd	nd	nd	nd	nd	Wak
Coa	-94.0891667	17.94	1	nd	nd	nd	nd	nd	nd	nd	1
Coa	-94.1669444	17.6086111	1	nd	nd	nd	nd	nd	nd	nd	1
Coa	-94.6861111	17.1941667	1	nd	nd	nd	nd	nd	nd	nd	2
Coa	-94.7897222	17.4722222	1	nd	nd	nd	nd	nd	nd	nd	2
G-U	-90.8055556	18.1269444	1	nd	nd	nd	nd	nd	nd	nd	3
G-U	-91.9	18.5072222	1	nd	nd	nd	nd	nd	nd	nd	3

Basin: G-U (Grijalva-Usumacinta); Coa (Coatzacoalcos)

Occurrence: 1 Present; 0 Abscent

nd: no data available.

*Source: * directly obtained; RG obtained by the research group, Capps (Capps et al., 2011), Wak (Wakida-Kusunoki et al., 2007), 1 (Martínez Torruco, 2011), 2 (Aguilar, 2011), 3 (Sucesión online diario, 2012)*

Appendix 2. Occurrences in the Native range for Loricariids (set named NATIVE OCCURRENCES). Obtained online from the Global Biodiversity Information Facility database (GBIF, 2012)

Family	Longitude	Latitude
Loricariidae	-74.9333	-9.61667
Loricariidae	-74.9333	-9.61667
Loricariidae	-74.9333	-9.61667
Loricariidae	-74.95	-9.61667
Loricariidae	-74.933	-9.65
Loricariidae	-74.9167	-9.61667
Loricariidae	-74.95	-9.61667
Loricariidae	-74.9333	-9.61667
Loricariidae	-74.95	-9.61667
Loricariidae	-74.9333	-9.61667
Loricariidae	-74.9333	-9.61667
Loricariidae	-57.2167	-25.9833
Loricariidae	-74.4	-4.8833
Loricariidae	-76.1833	-2.55
Loricariidae	-57.3369	-34.3186
Loricariidae	-57.3369	-34.3186
Loricariidae	-57.3369	-34.3186
Loricariidae	-57.3369	-34.3186
Loricariidae	-57.3369	-34.3186
Loricariidae	-58.1614	-20.2167
Loricariidae	-57.3369	-34.3186
Loricariidae	-56.3078	-25.6822
Loricariidae	-56.0097	-25.3875
Loricariidae	-55.2714	-26.4775
Loricariidae	-56.0022	-25.5047
Loricariidae	-57.4367	-23.6078
Loricariidae	-57.8367	-22.4422
Loricariidae	-54.8006	-33.1897
Loricariidae	-57.9503	-22.0872
Loricariidae	-57.4603	-23.6217

Longitude	Latitude
-57.2817	-24.0008
-57.9503	-22.0872
-57.9503	-22.0872
-57.5464	-25.13
-57.2817	-24.0008
-58.0169	-22.1122
-57.79	-22.9456
-57.79	-22.9456
-53.7292	-32.1419
-54.8006	-33.1897
-57.8528	-22.3994
-57.8842	-22.2436
-57.6294	-23.1575
-57.7983	-22.4014
-57.8061	-22.4039
-57.2947	-24.8406
-57.2756	-24.152
-57.1772	-24.5911
-57.1661	-24.4992
-58.0194	-26.1092
-58.0194	-26.1092
-58.0194	-26.1092
-57.7453	-25.8147
-55.795	-25.3911
-56.1789	-25.3247
-58.1614	-20.2167
-79.7447	-2.9814
-53.75	-32.1667
-53.75	-32.1667
-57.79	-22.9456

Longitude	Latitude
-57.9614	-31.4077
-56	-1.5
-69.7	9.2
-70.2333	8.75
-70.25	8.7667
-69.7	9.25
-69.6667	9.2833
-69.7	9.2
-69.7	9.2
-69.7	9.2
-69.1	8.9333
-69.7	9.25
-69.1	8.9333
-77.7833	-4.01667
-62.4167	8.53333
-61.4167	8.48333
-62.445	8.52667
-62.2633	8.57
-62.1867	8.695
-61.975	8.675
-62.0067	8.67833
-62.7	8.375
-61.9833	8.66
-61.7925	8.62222
-61.7925	8.62222
-62.1833	8.71667
-62.1833	8.71667
-62.1833	8.71667
-63.6667	8.05
-63.6667	8.05

Longitude	Latitude
-64.25	8
-64.25	8
-64.25	8
-63.5322	8.16389
-62.2333	8.65667
-62.2333	8.65667
-62.1667	8.70083
-62.1667	8.7
-61.7908	8.6075
-61.7931	8.62194
-60.8706	8.61833
-61	8.60667
-61	8.60667
-60.8267	8.62667
-38.483	-12.967
-65.586	-10.732
-57.6685	-30.5516
-56.4035	-33.3973
-57.1141	-30.4557
-57.6685	-30.5516
-57.563	-31.3861
-77.4	-0.8
-77.4	-0.8
-40.9	-17.7
-77.4	-0.8
-40.9	-17.7
-77.4	-0.8
-40.4	-17.9
-40.9	-17.7
-40.1	-17.4

Family	Longitude	Latitude
Loricariidae	-77.4	-0.8
Loricariidae	-39.6	-17.6
Loricariidae	-39.6	-16.4
Loricariidae	-77.4	-0.8
Loricariidae	-40.2	-15.9
Loricariidae	-39.6	-16.4
Loricariidae	-39.6	-16.4
Loricariidae	-39.6	-16.4
Loricariidae	-40.9	-17.7
Loricariidae	-40.1	-17.4
Loricariidae	-40.9	-17.7
Loricariidae	-40.1	-17.4
Loricariidae	-67.4	6.2
Loricariidae	-67.4	6.2
Loricariidae	-47.3	-21.4
Loricariidae	-40.3	-17.8
Loricariidae	-40.3	-17.8
Loricariidae	-40.2	-15.9
Loricariidae	-60.9	8.6
Loricariidae	-48.4933	-1.435
Loricariidae	-57.7	-14.5
Loricariidae	-77.4	-0.8
Loricariidae	-77	-2
Loricariidae	-76.6	-2.4
Loricariidae	-67.5	7.9
Loricariidae	-49.1	-28
Loricariidae	-74.6	-8.3
Loricariidae	-74.6	-8.3
Loricariidae	-47.3	-15.4
Loricariidae	-66.3	-14.9

Longitude	Latitude
-69.345	8.8275
-67.3	8.9
-69.1472	-12.5
-57.1	5.8
-57.2	5.5
-63.5	-21.3
-64	-19.8
-63.2	-20
-64	-19.8
-64.2	-21.6
-58	3.7
-63.4	-20.9
-64	-19.8
-66.3	-14.9
-52.8	-32.4
-42.8	-22.9
-40.2	-15.4
-40.2	-15.4
-40	-16
-39.5	-17.1
-40.2	-17.9
-40.2	-17.9
-40	-16
-57.3	5
-57.5	4.8
-77.7	8.1
-66.3	-14.9
-78.3746	-5.77565
-57.9602	-31.3997
-46.32	-13.42

Longitude	Latitude
-52.1167	4.3
-77.826	-1.919
-77.826	-1.919
-76.422	-3.7
-69.075	-11.276
-67.563	-11.192
-67.563	-11.192
-57.933	-20.8
-61.008	-13.535
-78.433	-3.917
-67.563	-11.192
-57.967	-21.85
-57.267	-22.233
-67.563	-11.192
-57.267	-22.233
-68.743	-11.314
-61.008	-13.535
-68.75	-11.314
-56.52	4.421
-56.452	4.31
-67.023	4.005
-67.023	4.005
-73.341	-11.78
-68.743	-11.314
-78.433	-3.917
-57.933	-20.8
-68.75	-11.314
-69.029	-11.449
-69.075	-11.276
-61.008	-13.535

Longitude	Latitude
-69.029	-11.449

Appendix 3. Correlation Matrix. The high correlated pair of variables is shaded (*r >0.7*)

	suelos	tmppc	tmppf	tpa	tpcc	tpcf	tpcll	tpcs	veget
suelos	1	0.03545	0.13718	0.06119	0.07242	0.02558	0.05822	0.14318	-0.01204
tmppc	0.03545	1	0.87117	0.97125	0.97814	0.95708	0.97253	0.92374	0.13427
tmppf	0.13718	0.87117	1	0.94987	0.94587	0.93101	0.95037	0.97295	0.18384
tpa	0.06119	0.97125	0.94987	1	0.99697	0.99182	0.99579	0.9671	0.12917
tpcc	0.07242	0.97814	0.94587	0.99697	1	0.98067	0.99576	0.97142	0.13787
tpcf	0.02558	0.95708	0.93101	0.99182	0.98067	1	0.98282	0.9399	0.10567
tpcll	0.05822	0.97253	0.95037	0.99579	0.99576	0.98282	1	0.96621	0.1572
tpcs	0.14318	0.92374	0.97295	0.9671	0.97142	0.9399	0.96621	1	0.15548
veget	-0.01204	0.13427	0.18384	0.12917	0.13787	0.10567	0.1572	0.15548	1
oat	-0.1892	0.36229	-0.14174	0.15505	0.17653	0.16229	0.15668	0.01544	-0.07831
odt	-0.25512	-0.06834	-0.4927	-0.21754	-0.23106	-0.15795	-0.23684	-0.38787	-0.22956
pa	0.22738	0.15338	0.36273	0.18876	0.21329	0.12378	0.20083	0.3483	0.19936
pcc	0.11908	-0.10912	0.09727	-0.089	-0.07159	-0.13924	-0.05692	0.04238	0.28082
pcf	0.30638	0.30671	0.53741	0.36853	0.38957	0.29502	0.36939	0.5486	0.16689
pcll	0.15312	0.12502	0.30149	0.14969	0.17745	0.09358	0.16886	0.28259	0.16075
pcs	0.31135	0.1896	0.43176	0.24677	0.26522	0.17515	0.25401	0.41242	0.23605
ppll	0.1919	0.12395	0.30707	0.15516	0.18305	0.09856	0.16999	0.27987	0.15787
pps	0.14833	0.10955	0.23189	0.12952	0.1431	0.08222	0.13098	0.24033	0.12107
iso	-0.19717	-0.5478	-0.64382	-0.54758	-0.59521	-0.4585	-0.5802	-0.65898	-0.27855
ndvi	-0.05436	0.22578	0.21856	0.22845	0.22369	0.23641	0.23294	0.17475	0.1574
area	-0.10299	-0.3074	-0.41969	-0.32392	-0.35283	-0.26865	-0.36224	-0.39663	-0.21931
ep	-0.35298	-0.21992	-0.45005	-0.28476	-0.29688	-0.21417	-0.28316	-0.44348	-0.25288
flowacc	0.00429	0.04908	0.04824	0.04981	0.04923	0.04995	0.04844	0.04662	-0.01967
flowdir	0.03539	-0.02656	0.03039	-0.00387	-0.00731	-0.00473	-0.00433	0.01636	0.03907
alt	-0.12932	-0.93921	-0.94215	-0.95807	-0.96778	-0.92718	-0.96451	-0.96217	-0.17666
et	0.221	0.74492	0.73242	0.71952	0.76557	0.6266	0.7444	0.7983	0.20815

Continuation of Appendix 3

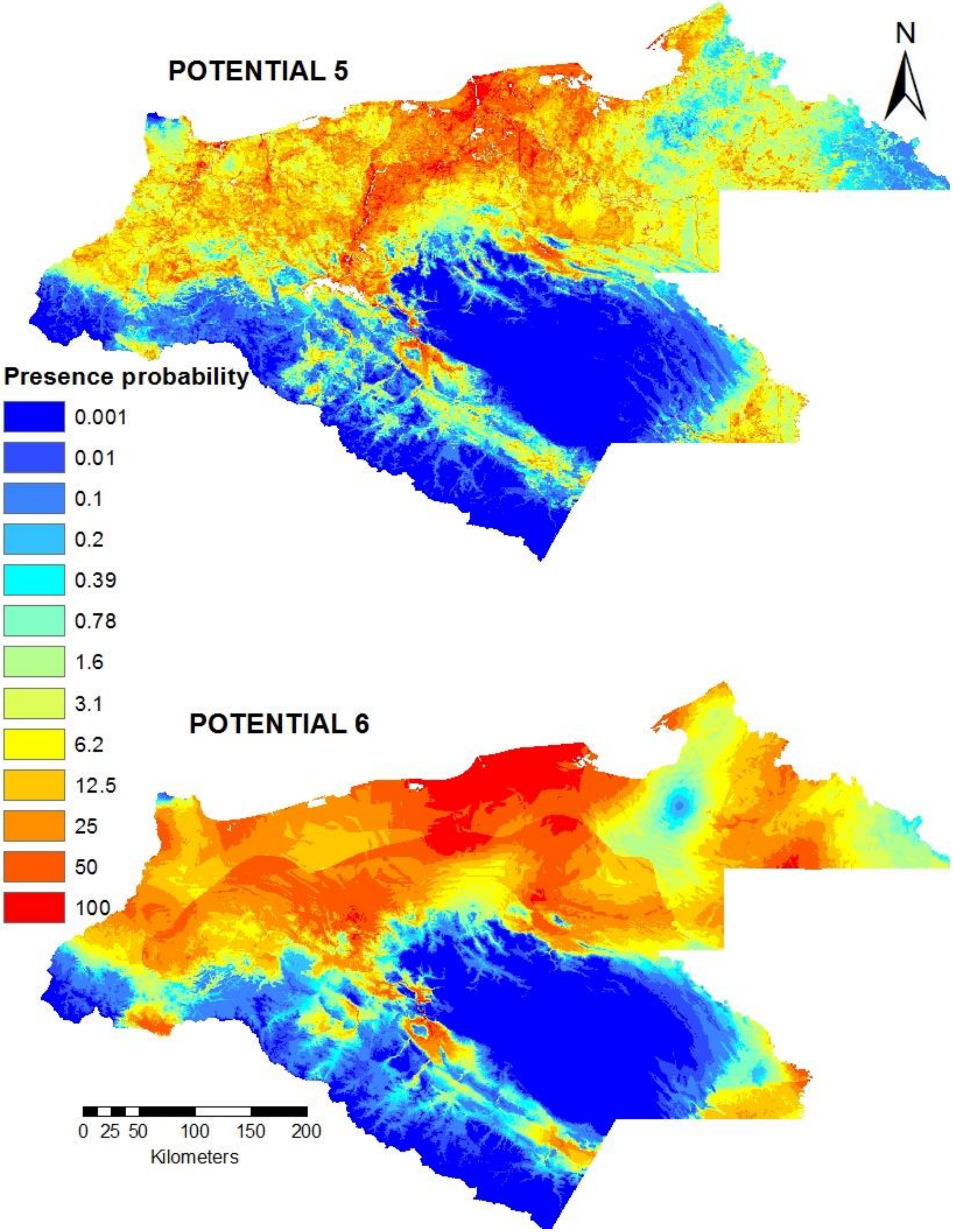
	oat	odt	pa	pcc	pcf	pcll	pcs	ppll	pps
suelos	-0.1892	-0.25512	0.22738	0.11908	0.30638	0.15312	0.31135	0.1919	0.14833
tmppc	0.36229	-0.06834	0.15338	-0.10912	0.30671	0.12502	0.1896	0.12395	0.10955
tmppf	-0.14174	-0.4927	0.36273	0.09727	0.53741	0.30149	0.43176	0.30707	0.23189
tpa	0.15505	-0.21754	0.18876	-0.089	0.36853	0.14969	0.24677	0.15516	0.12952
tpcc	0.17653	-0.23106	0.21329	-0.07159	0.38957	0.17745	0.26522	0.18305	0.1431
tpcf	0.16229	-0.15795	0.12378	-0.13924	0.29502	0.09358	0.17515	0.09856	0.08222
tpcll	0.15668	-0.23684	0.20083	-0.05692	0.36939	0.16886	0.25401	0.16999	0.13098
tpcs	0.01544	-0.38787	0.3483	0.04238	0.5486	0.28259	0.41242	0.27987	0.24033
veget	-0.07831	-0.22956	0.19936	0.28082	0.16689	0.16075	0.23605	0.15787	0.12107
oat	1	0.79771	-0.37947	-0.40483	-0.40188	-0.32044	-0.43745	-0.33321	-0.21942
odt	0.79771	1	-0.66467	-0.57043	-0.69166	-0.62211	-0.6591	-0.62686	-0.3744
pa	-0.37947	-0.66467	1	0.88097	0.87955	0.93947	0.87105	0.91662	0.75486
pcc	-0.40483	-0.57043	0.88097	1	0.65797	0.84627	0.74035	0.81558	0.66878
pcf	-0.40188	-0.69166	0.87955	0.65797	1	0.71073	0.93681	0.69054	0.75596
pcll	-0.32044	-0.62211	0.93947	0.84627	0.71073	1	0.68452	0.97725	0.60877

pcs	-0.43745	-0.6591	0.87105	0.74035	0.93681	0.68452	1	0.68831	0.82465
ppll	-0.33321	-0.62686	0.91662	0.81558	0.69054	0.97725	0.68831	1	0.58751
pps	-0.21942	-0.3744	0.75486	0.66878	0.75596	0.60877	0.82465	0.58751	1
iso	0.11785	0.69028	-0.63413	-0.44218	-0.65357	-0.63722	-0.55496	-0.63034	-0.34677
ndvi	0.04014	-0.03613	0.09422	0.10122	0.02937	0.11073	0.09377	0.13605	0.1044
area	0.17691	0.50829	-0.27209	-0.2093	-0.30721	-0.31107	-0.21122	-0.32195	0.02786
ep	0.41097	0.5715	-0.58878	-0.43359	-0.81111	-0.31699	-0.85107	-0.33099	-0.56887
flowacc	0.00733	-0.00591	0.00932	-0.00646	0.02123	0.00168	0.01876	0.00491	0.00333
flowdir	-0.11135	-0.09014	0.08829	0.08953	0.09321	0.0703	0.1018	0.06634	0.0836
alt	-0.10511	0.32912	-0.31602	-0.0385	-0.46797	-0.28428	-0.34879	-0.28603	-0.17005
et	0.11152	-0.44761	0.46486	0.19365	0.62443	0.4059	0.5213	0.41016	0.32318

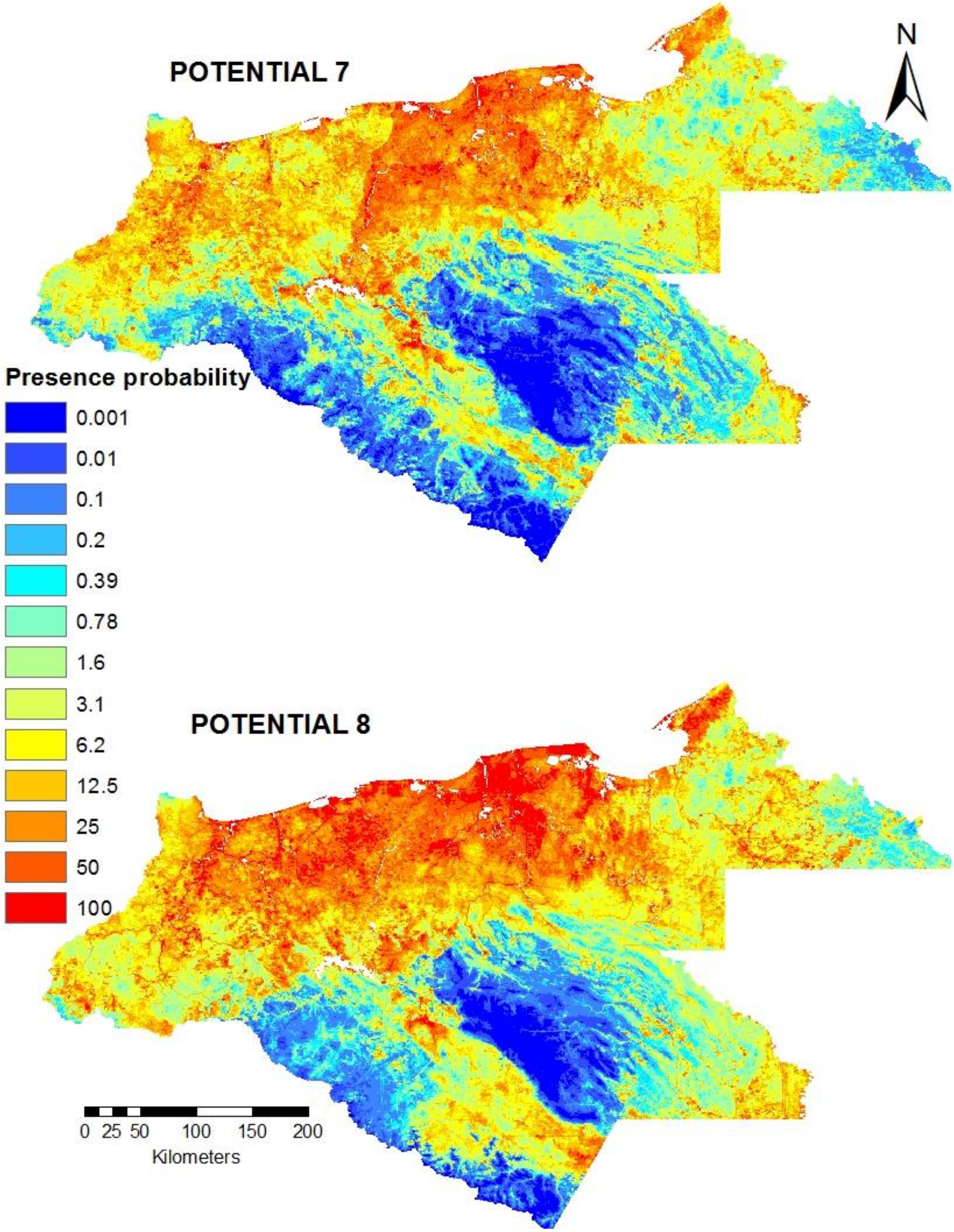
Continuation of Appendix 3.

	iso	ndvi	area	ep	flowacc	flowdir	alt	et
suelos	-0.19717	-0.05436	-0.10299	-0.35298	0.00429	0.03539	-0.12932	0.221
tmppc	-0.5478	0.22578	-0.3074	-0.21992	0.04908	-0.02656	-0.93921	0.74492
tmppf	-0.64382	0.21856	-0.41969	-0.45005	0.04824	0.03039	-0.94215	0.73242
tpa	-0.54758	0.22845	-0.32392	-0.28476	0.04981	-0.00387	-0.95807	0.71952
tpcc	-0.59521	0.22369	-0.35283	-0.29688	0.04923	-0.00731	-0.96778	0.76557
tpcf	-0.4585	0.23641	-0.26865	-0.21417	0.04995	-0.00473	-0.92718	0.6266
tpcll	-0.5802	0.23294	-0.36224	-0.28316	0.04844	-0.00433	-0.96451	0.7444
tpcs	-0.65898	0.17475	-0.39663	-0.44348	0.04662	0.01636	-0.96217	0.7983
veget	-0.27855	0.1574	-0.21931	-0.25288	-0.01967	0.03907	-0.17666	0.20815
oat	0.11785	0.04014	0.17691	0.41097	0.00733	-0.11135	-0.10511	0.11152
odt	0.69028	-0.03613	0.50829	0.5715	-0.00591	-0.09014	0.32912	-0.44761
pa	-0.63413	0.09422	-0.27209	-0.58878	0.00932	0.08829	-0.31602	0.46486
pcc	-0.44218	0.10122	-0.2093	-0.43359	-0.00646	0.08953	-0.0385	0.19365
pcf	-0.65357	0.02937	-0.30721	-0.81111	0.02123	0.09321	-0.46797	0.62443
pcll	-0.63722	0.11073	-0.31107	-0.31699	0.00168	0.0703	-0.28428	0.4059
pcs	-0.55496	0.09377	-0.21122	-0.85107	0.01876	0.1018	-0.34879	0.5213
ppll	-0.63034	0.13605	-0.32195	-0.33099	0.00491	0.06634	-0.28603	0.41016
pps	-0.34677	0.1044	0.02786	-0.56887	0.00333	0.0836	-0.17005	0.32318
iso	1	-0.10673	0.62228	0.44264	-0.01873	-0.01405	0.67051	-0.87041
ndvi	-0.10673	1	-0.01009	0.00057	-0.00183	0.00289	-0.23245	0.10727
area	0.62228	-0.01009	1	0.22588	-0.02097	-0.01416	0.44914	-0.53106
ep	0.44264	0.00057	0.22588	1	-0.02691	-0.08911	0.37426	-0.52916
flowacc	-0.01873	-0.00183	-0.02097	-0.02691	1	0.0325	-0.04895	0.03245
flowdir	-0.01405	0.00289	-0.01416	-0.08911	0.0325	1	0.00196	-0.0053
alt	0.67051	-0.23245	0.44914	0.37426	-0.04895	0.00196	1	-0.81521
et	-0.87041	0.10727	-0.53106	-0.52916	0.03245	-0.0053	-0.81521	1

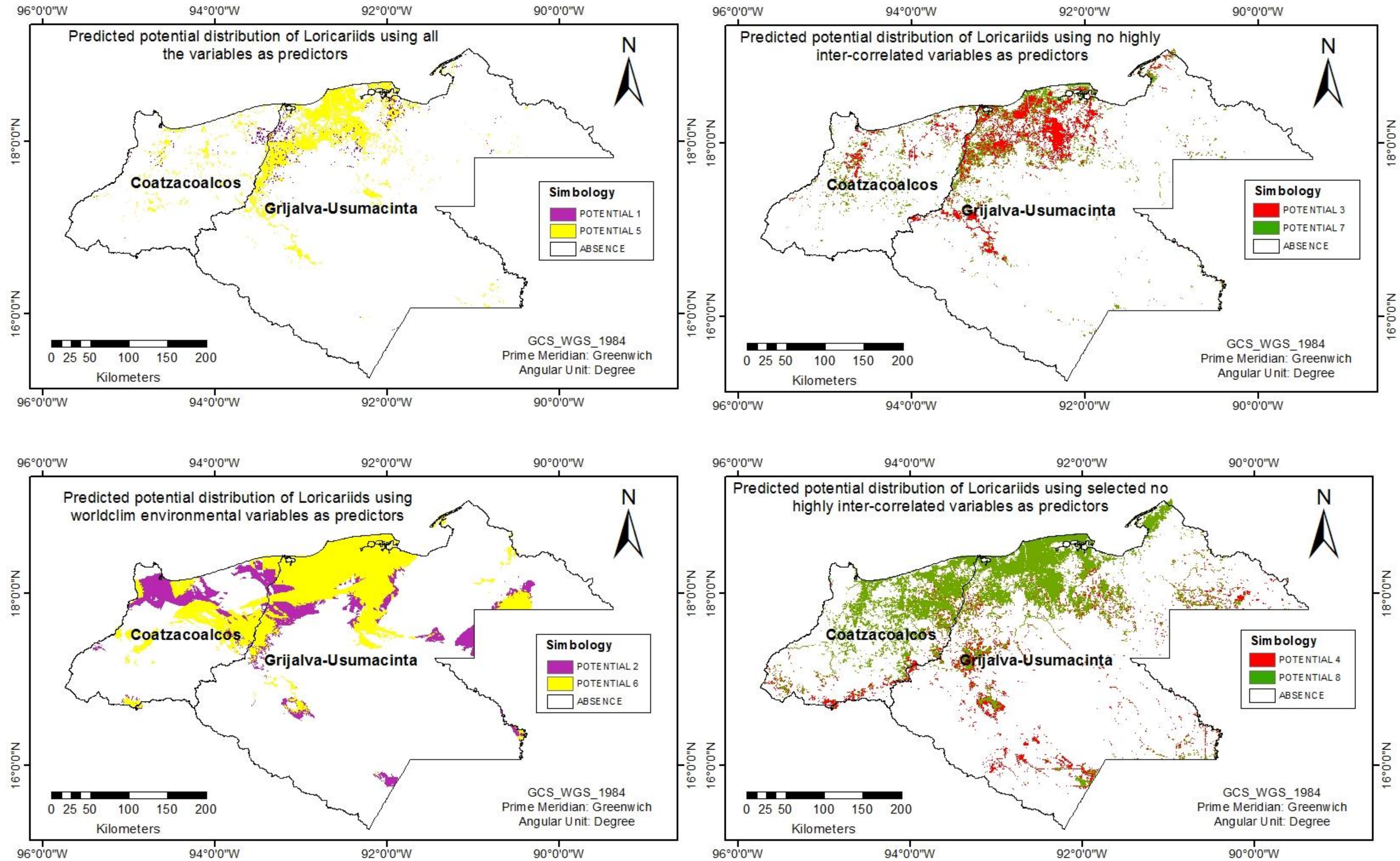
Appendix 4. Maxent predicted probability for models POTENTIAL 5, 6, 7 8.



Continuation of Appendix 4



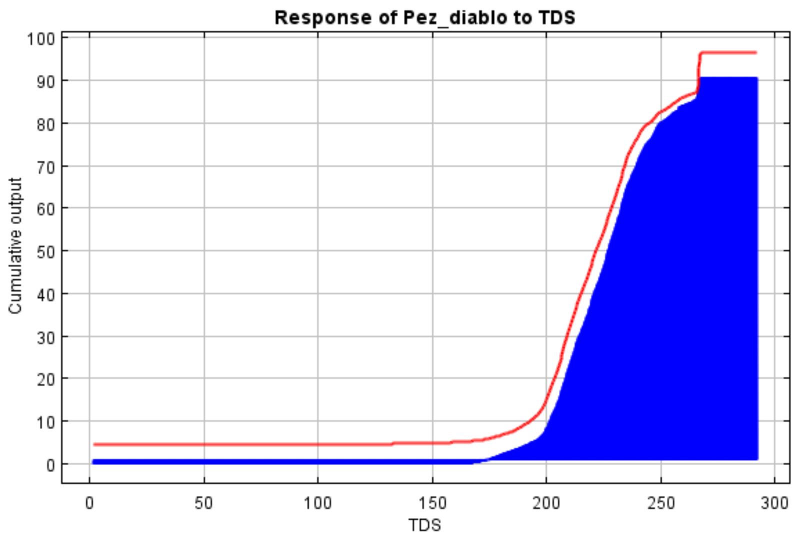
Appendix 5. Pair-wise comparison of presence/absence models sharing the same set of predictors but using different occurrence sets.

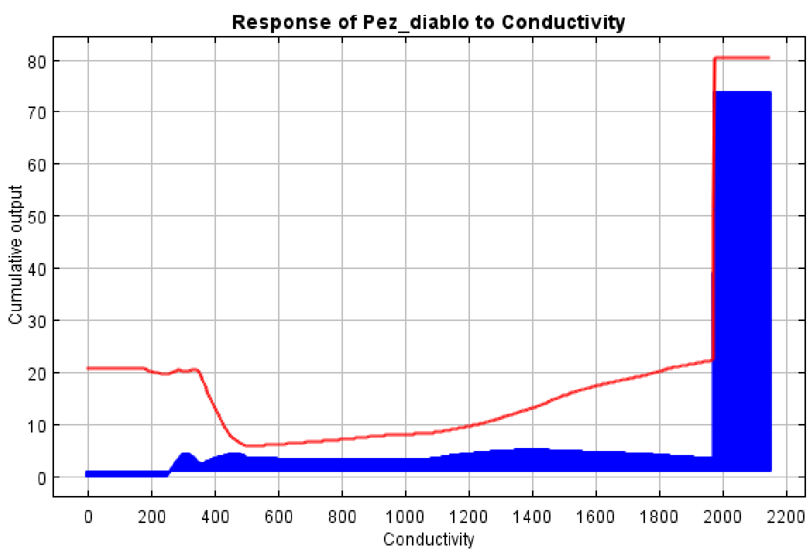


Appendix 6. Response curves of Devil Fish ("pez diablo") to physicochemical parameters of the water. Comparison between two set of occurrence data.

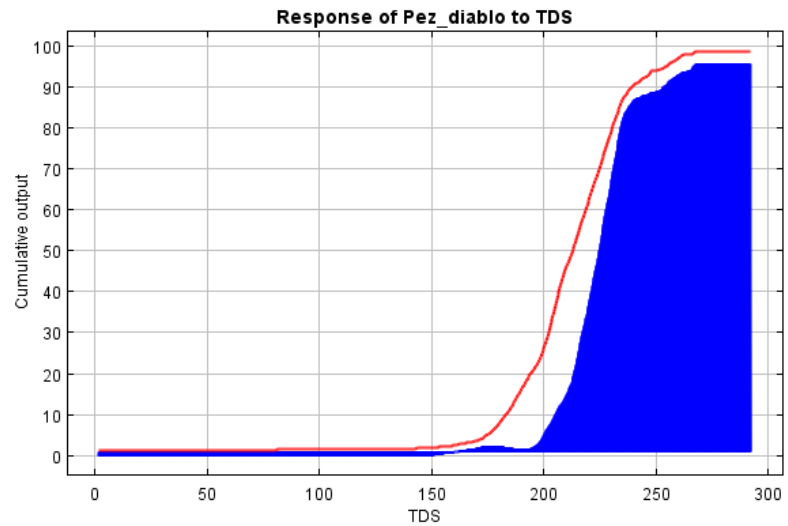
PHYSICOCHEMICAL 1	PHYSICOCHEMICAL 2

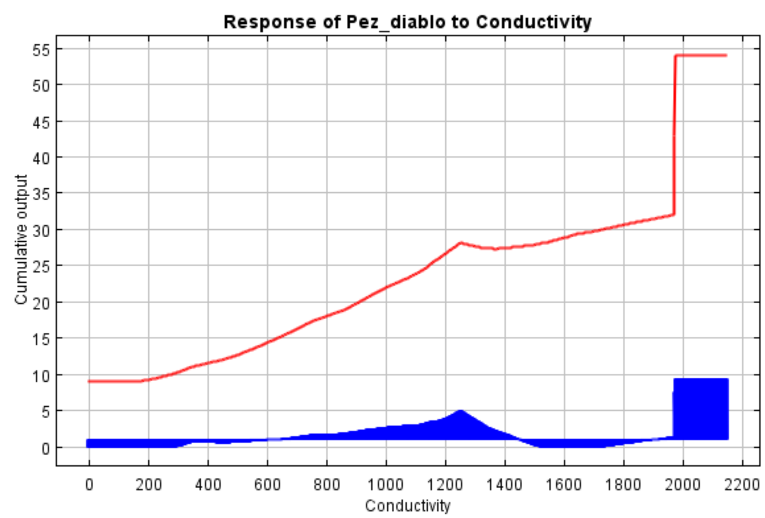
PHYSICOCHEMICAL 1

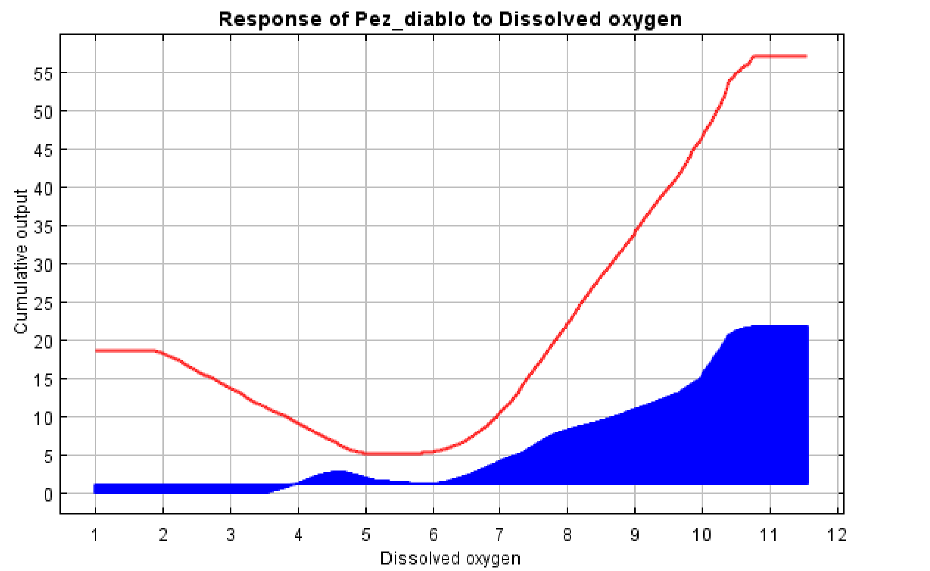


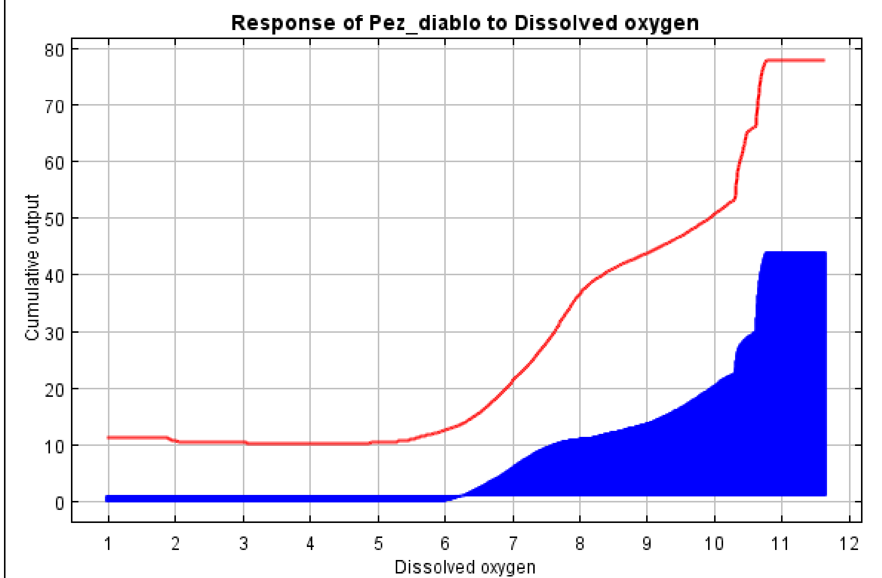


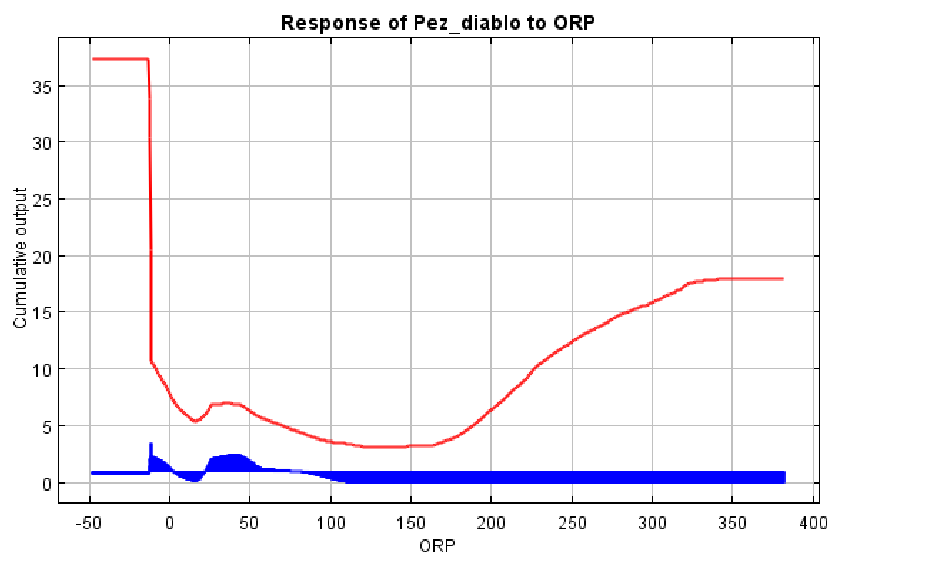
PHYSICOCHEMICAL 2

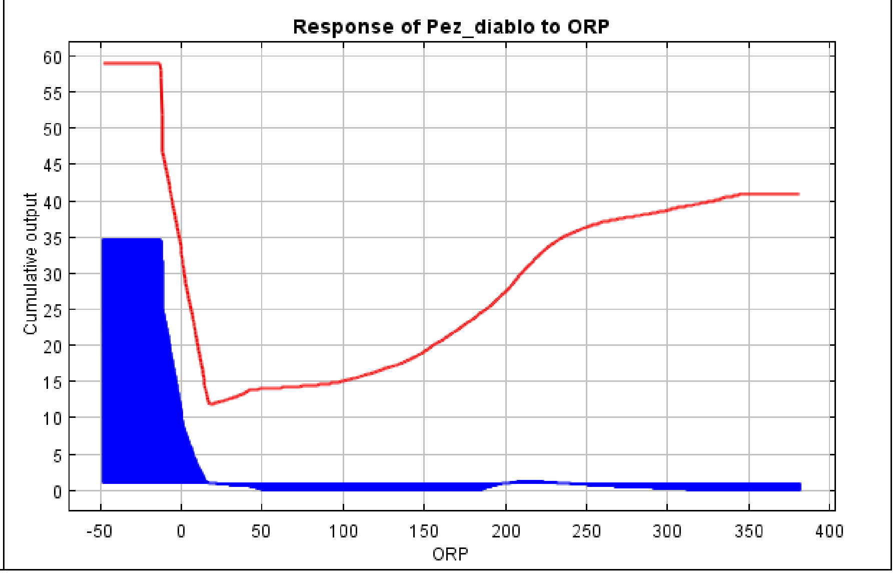


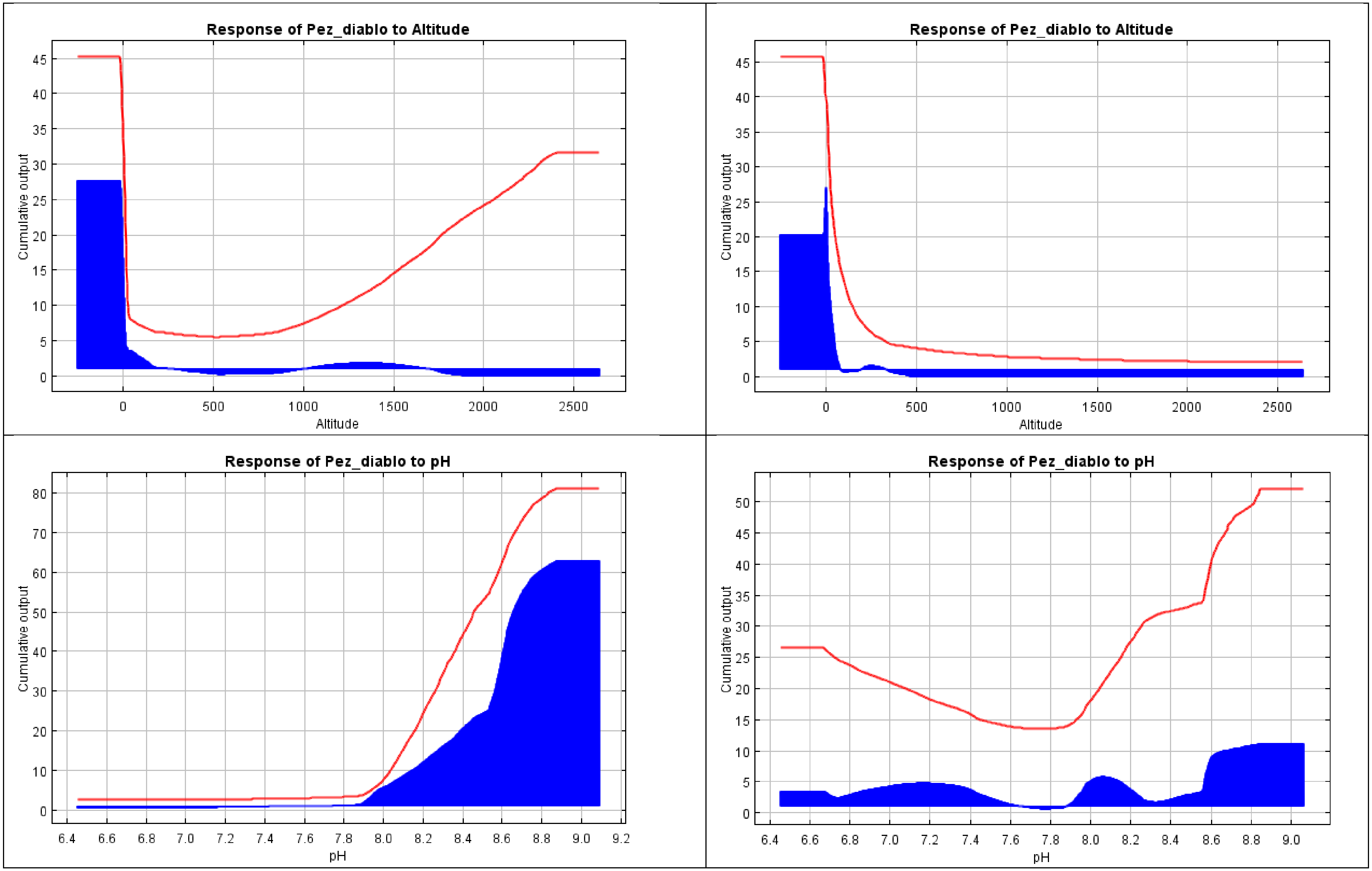


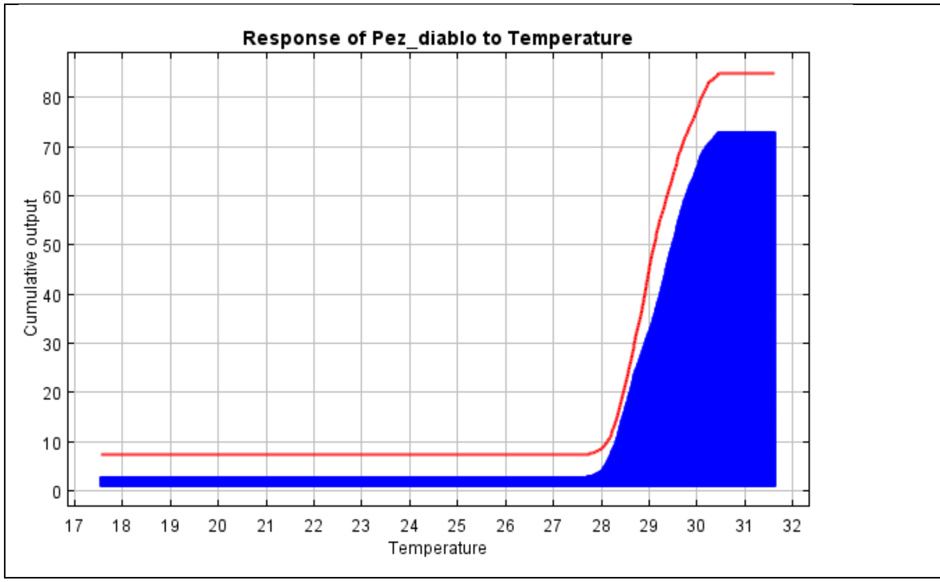

Response of Pez_diablo to Dissolved oxygen
Cumulative output
Dissolved oxygen

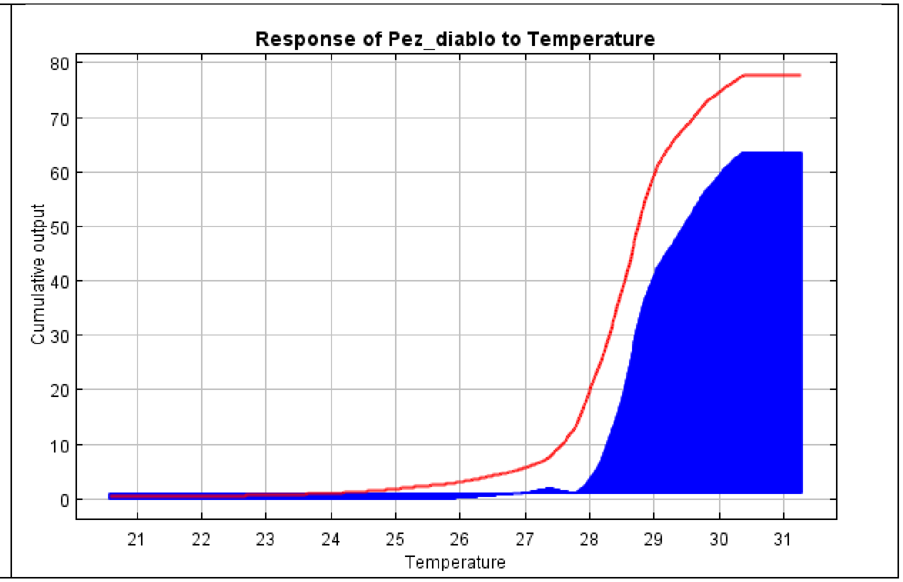

Response of Pez_diablo to Dissolved oxygen
Cumulative output
Dissolved oxygen


Response of Pez_diablo to ORP
Cumulative output
ORP

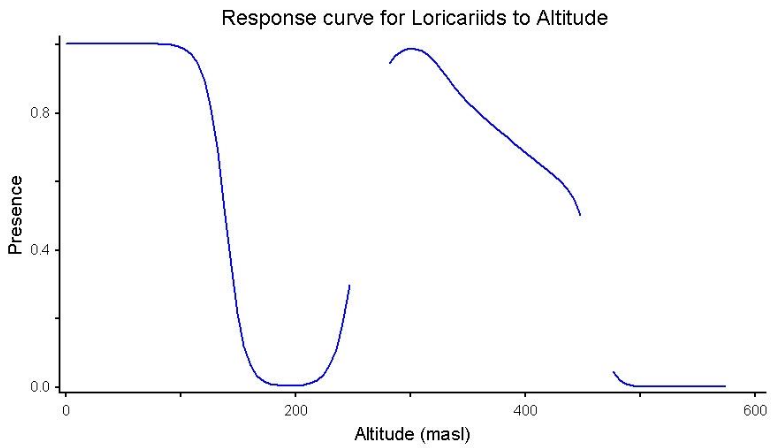

Response of Pez_diablo to ORP
Cumulative output
ORP

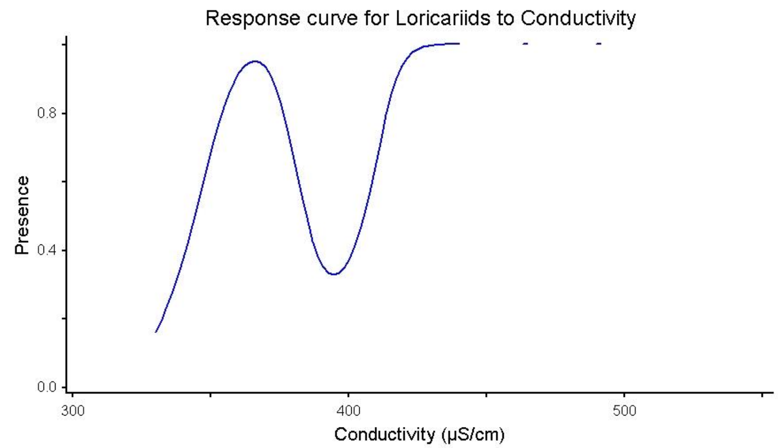

Response of Pez_diablo to Altitude
Cumulative output
45
40
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
2500
Altitude
Response of Pez_diablo to Altitude
Cumulative output
45
40
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
2500
Altitude
Response of Pez_diablo to pH
Cumulative output
80
70
60
50
40
30
20
10
0
6.4
6.6
6.8
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
8.6
8.8
9.0
9.2
pH
Response of Pez_diablo to pH
Cumulative output
50
45
40
35
30
25
20
15
10
5
0
6.4
6.6
6.8
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
8.6
8.8
9.0
pH

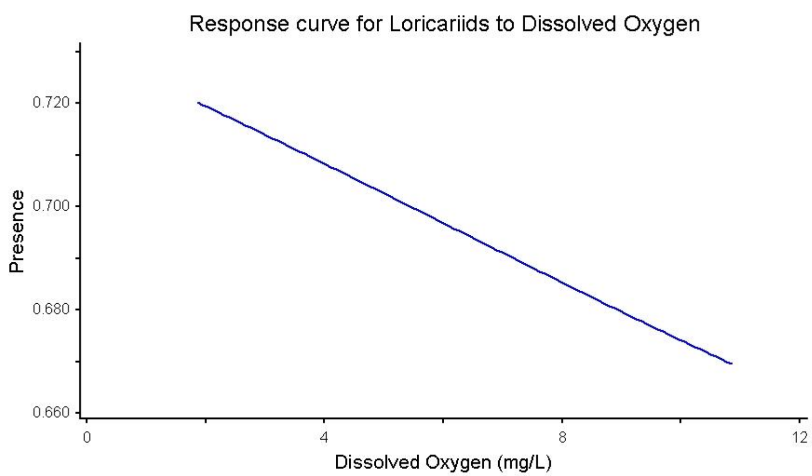

Response of Pez_diablo to Temperature
Cumulative output
0 10 20 30 40 50 60 70 80
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Temperature

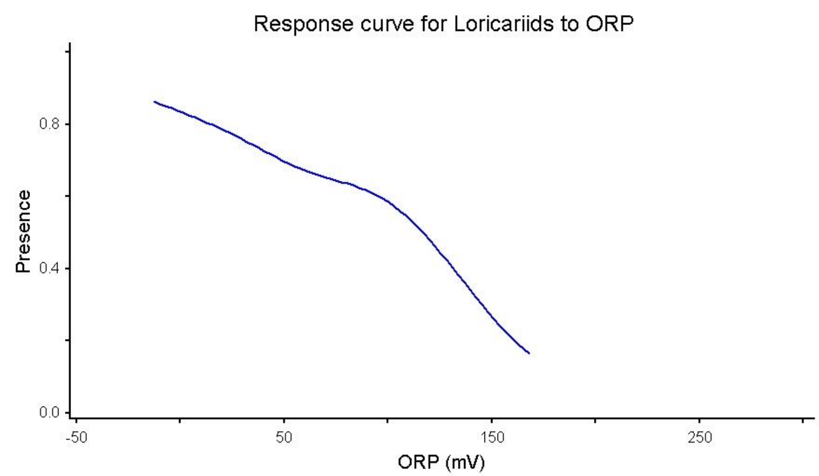

Response of Pez_diablo to Temperature
Cumulative output
0 10 20 30 40 50 60 70 80
21 22 23 24 25 26 27 28 29 30 31
Temperature

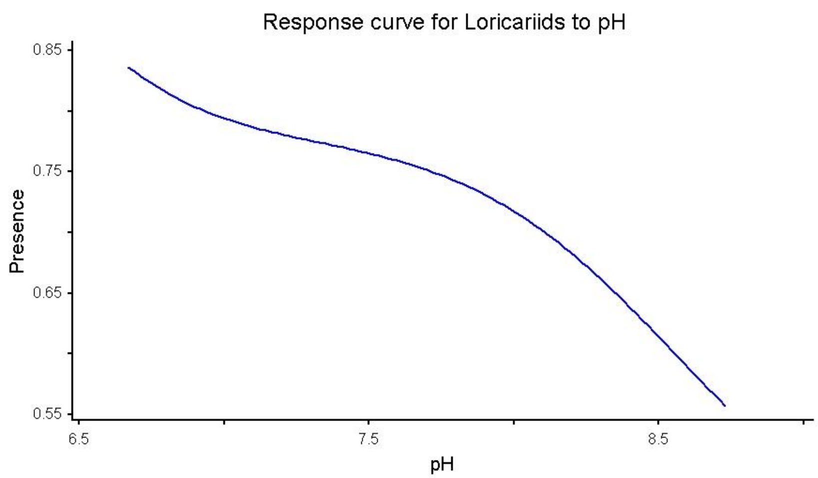
Appendix 7. Response curves of Loricariids to physicochemical variables using Hyperniche

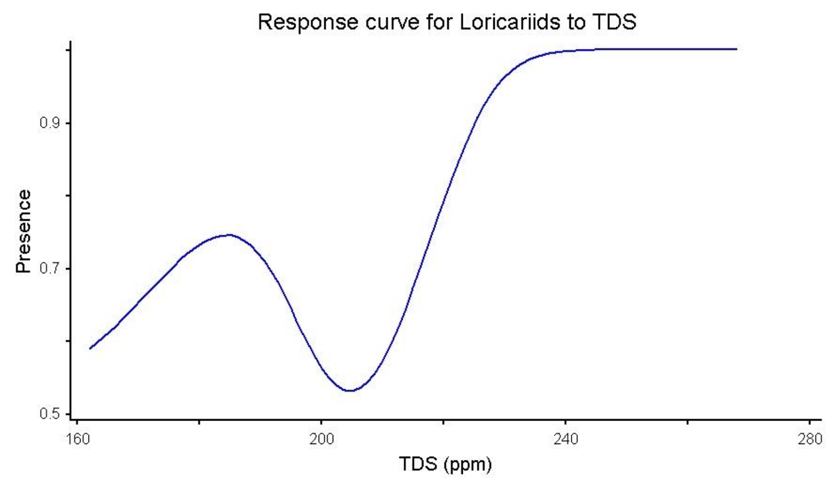


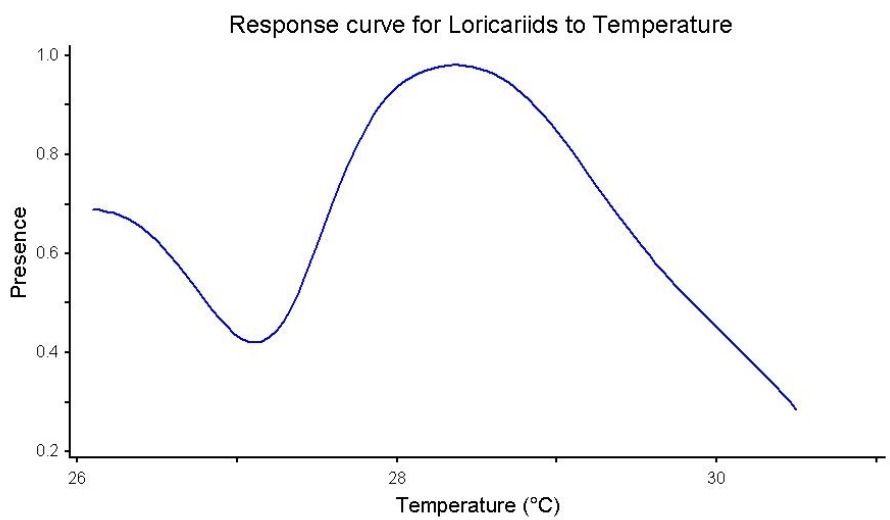







Response curve for Loricariids to pH
Presence
0.85
0.75
0.65
0.55
6.5
7.5
8.5
pH


Response curve for Loricariids to TDS
Presence
0.9
0.7
0.5
160
200
240
280
TDS (ppm)


Response curve for Loricariids to Temperature
Presence
1.0
0.8
0.6
0.4
0.2
26
28
30
Temperature (°C)

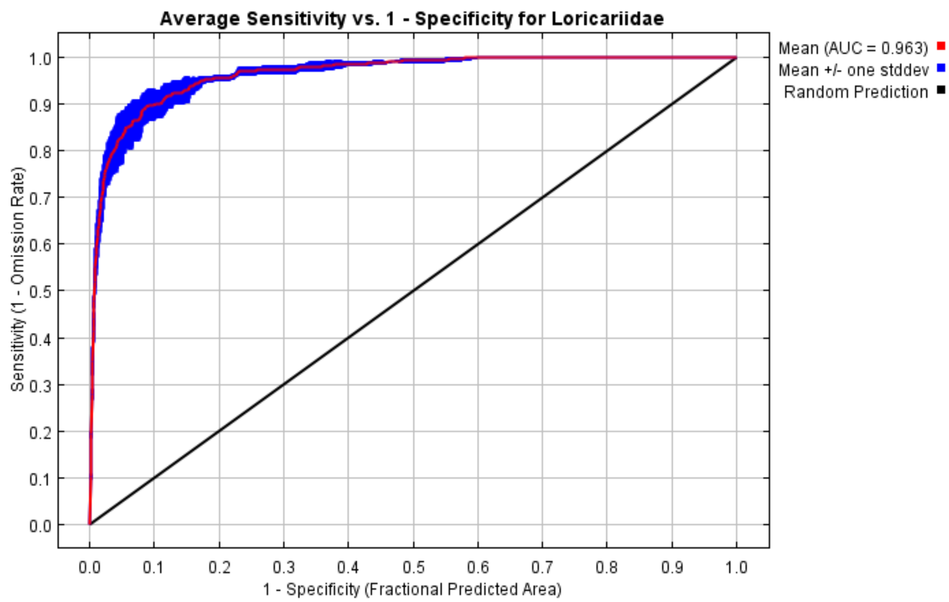
Appendix 8. AUC values for the five-fold Maxent runs for models POTENTIAL 1-8 and NATIVE 1 & 2. Green Highlighted: AUC mean values for training data. Blue Highlighted: AUC mean values for test data.

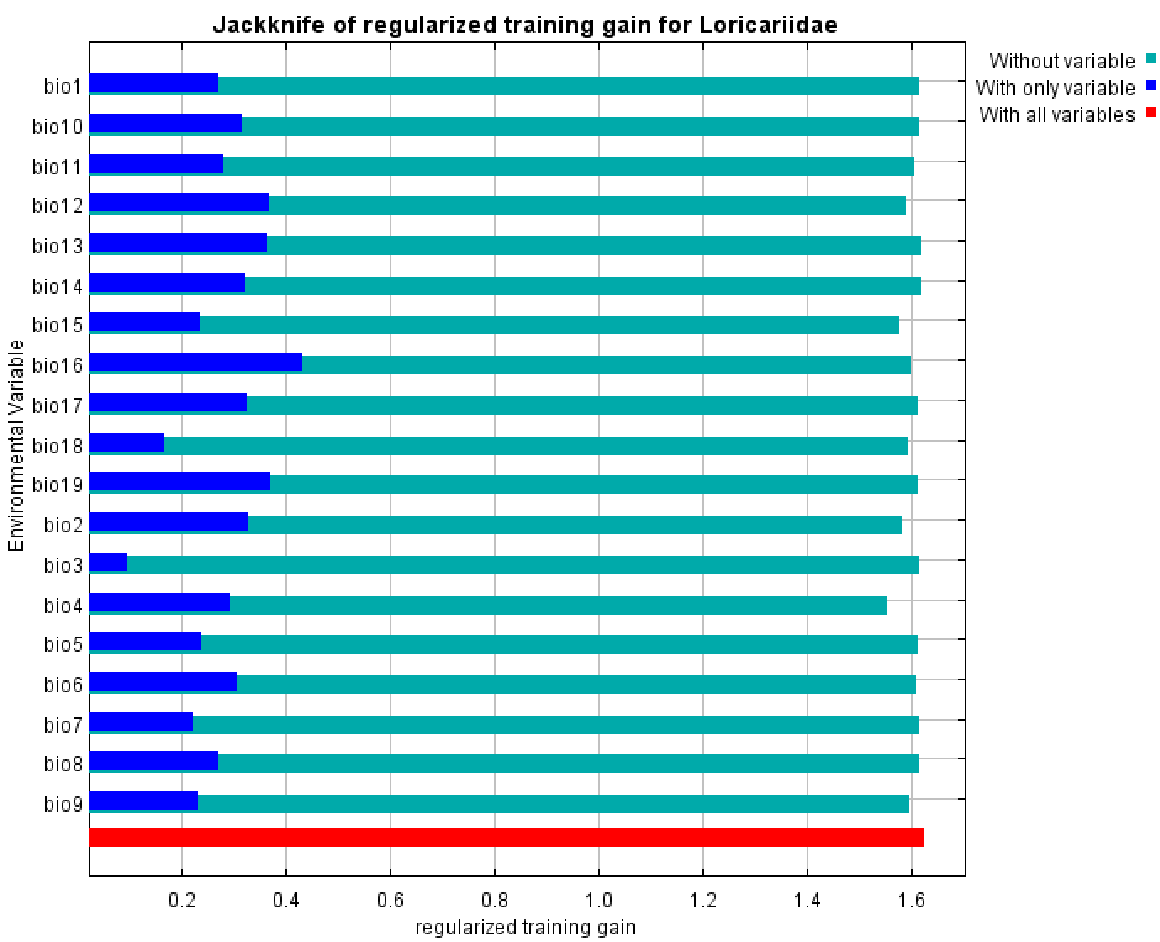
	All variables		Worldclim		No high correlated		After Jackknifing	
OCCURRENCES 1 (Directly obtained)	**POTENTIAL 1**		**POTENTIAL 2**		**POTENTIAL 3**		**POTENTIAL 4**	
	AUC Trai	***AUC Test***	***AUC Trai***	***AUC Test***	***AUC Trai***	***AUC Test***	***AUC Trai***	***AUC Test***
	0.991	0.976	0.969	0.916	0.988	0.981	0.953	0.878
	0.971	0.968	0.959	0.938	0.982	0.958	0.945	0.964
	0.99	0.965	0.965	0.916	0.986	0.95	0.871	0.94
	0.99	0.943	0.948	0.892	0.991	0.904	0.938	0.683
	0.996	0.942	0.946	0.92	0.966	0.922	0.921	0.938
	0.9876	**0.9588**	**0.9574**	**0.9164**	**0.9826**	**0.943**	**0.9256**	**0.8806**
OCCURRENCES 2 (Directly obtained and literature)	**POTENTIAL 5**		**POTENTIAL 6**		**POTENTIAL 7**		**POTENTIAL 8**	
	AUC Trai	***AUC Test***	***AUC Trai***	***AUC Test***	***AUC Trai***	***AUC Test***	***AUC Trai***	***AUC Test***
	0.957	0.872	0.958	0.945	0.954	0.919	0.933	0.934
	0.982	0.926	0.948	0.902	0.943	0.796	0.904	0.848
	0.976	0.954	0.932	0.865	0.951	0.961	0.929	0.876
	0.985	0.975	0.941	0.858	0.972	0.953	0.915	0.9
	0.984	0.909	0.956	0.946	0.963	0.964	0.932	0.96
	0.9768	**0.9272**	**0.947**	**0.9032**	**0.9566**	**0.9186**	**0.9226**	**0.9036**

NATIVE 1		NATIVE 2	
AUC Trai	***AUC Test***	***AUC Trai***	***AUC Test***
0.968	0.874	0.863	0.846
0.97	0.875	0.828	0.813
0.965	0.865	0.845	0.845
0.956	0.885	0.905	0.739
0.958	0.819	0.885	0.773
0.9634	**0.8636**	**0.8652**	**0.8032**

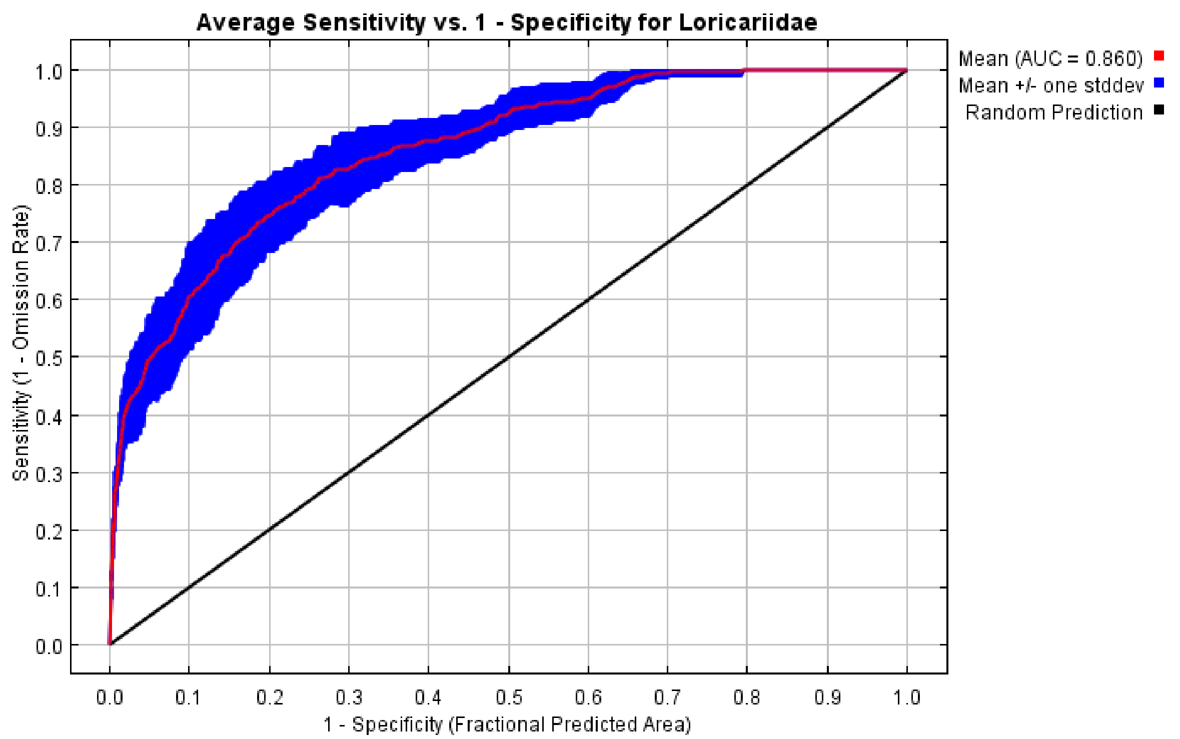
Appendix 9. ROC curves and Jackknife results for models NATIVE 1 & 2 and POTENTIAL 1,2,3,4,5,6,7 & 8.

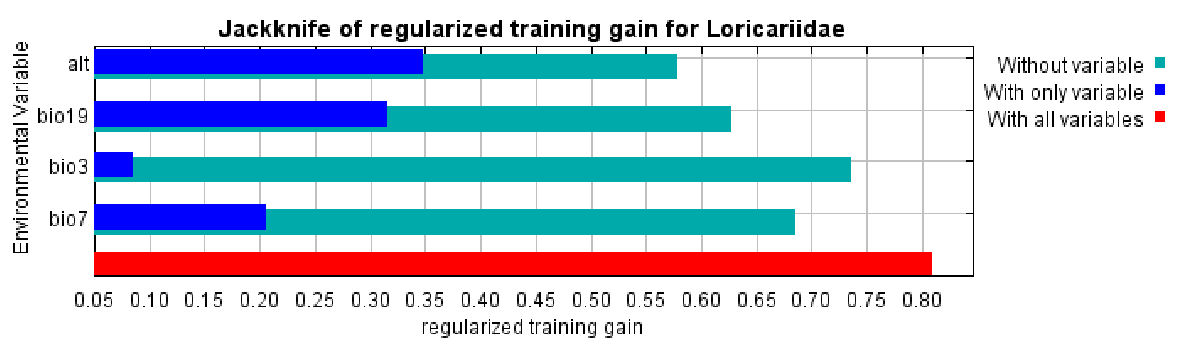
NATIVE 1



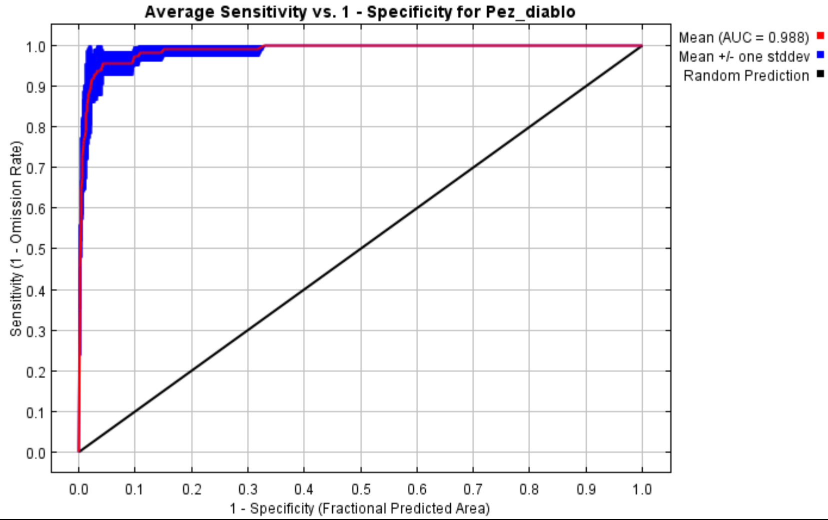


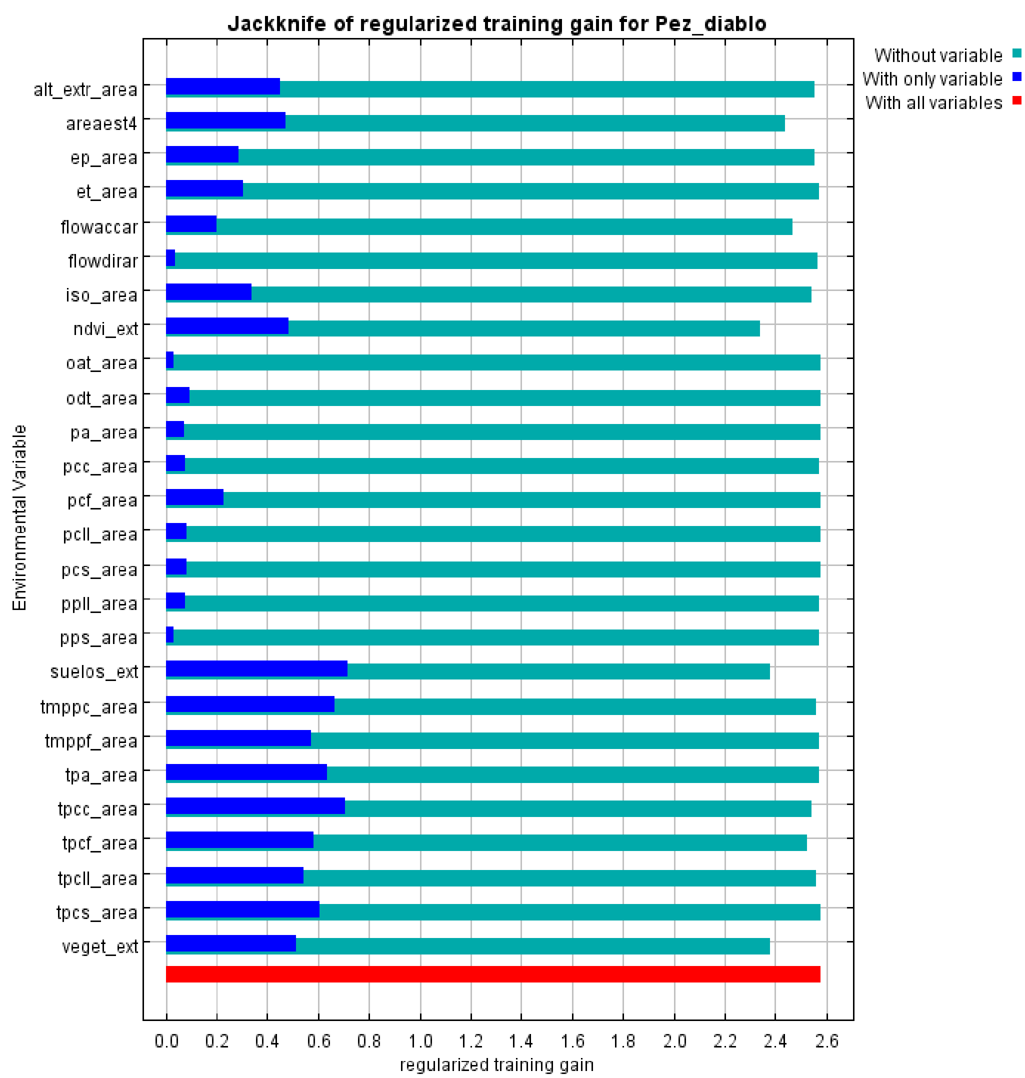
NATIVE 2


Average Sensitivity vs. 1 - Specificity for Loricariidae
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
Mean (AUC = 0.860)
Mean +/- one stddev
Random Prediction
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

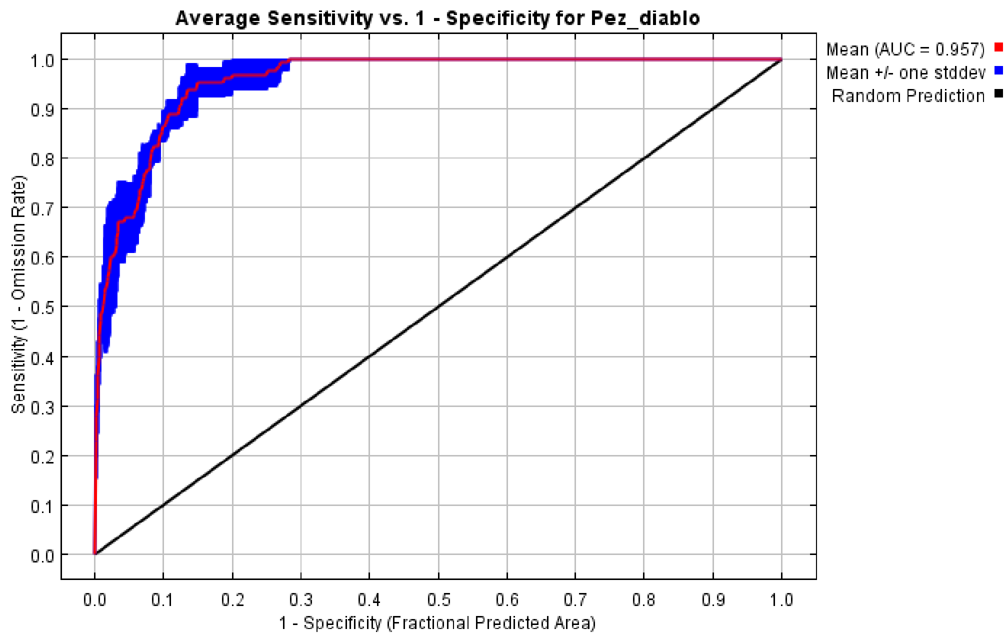

Jackknife of regularized training gain for Loricariidae
Environmental Variable
alt
bio19
bio3
bio7
regularized training gain
Without variable
With only variable
With all variables
0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80

POTENTIAL 1

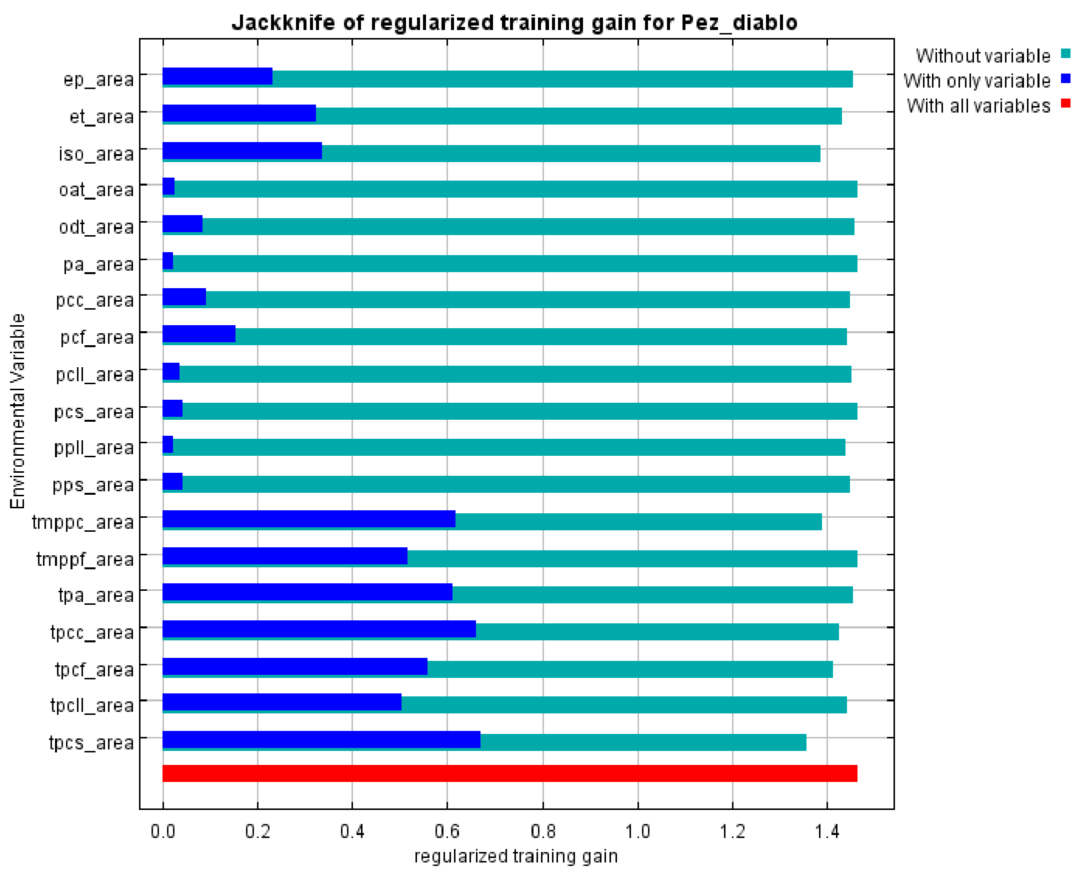

Average Sensitivity vs. 1 - Specificity for Pez_diablo
Mean (AUC = 0.988)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)


Jackknife of regularized training gain for Pez_diablo
Without variable
With only variable
With all variables
Environmental Variable
alt_extr_area
areaest4
ep_area
et_area
flowaccar
flowdirar
iso_area
ndvi_ext
oat_area
odt_area
pa_area
pcc_area
pcf_area
pcll_area
pcs_area
ppll_area
pps_area
suelos_ext
tmppc_area
tmppf_area
tpa_area
tpcc_area
tpcf_area
tpcll_area
tpcs_area
veget_ext
regularized training gain

POTENTIAL 2

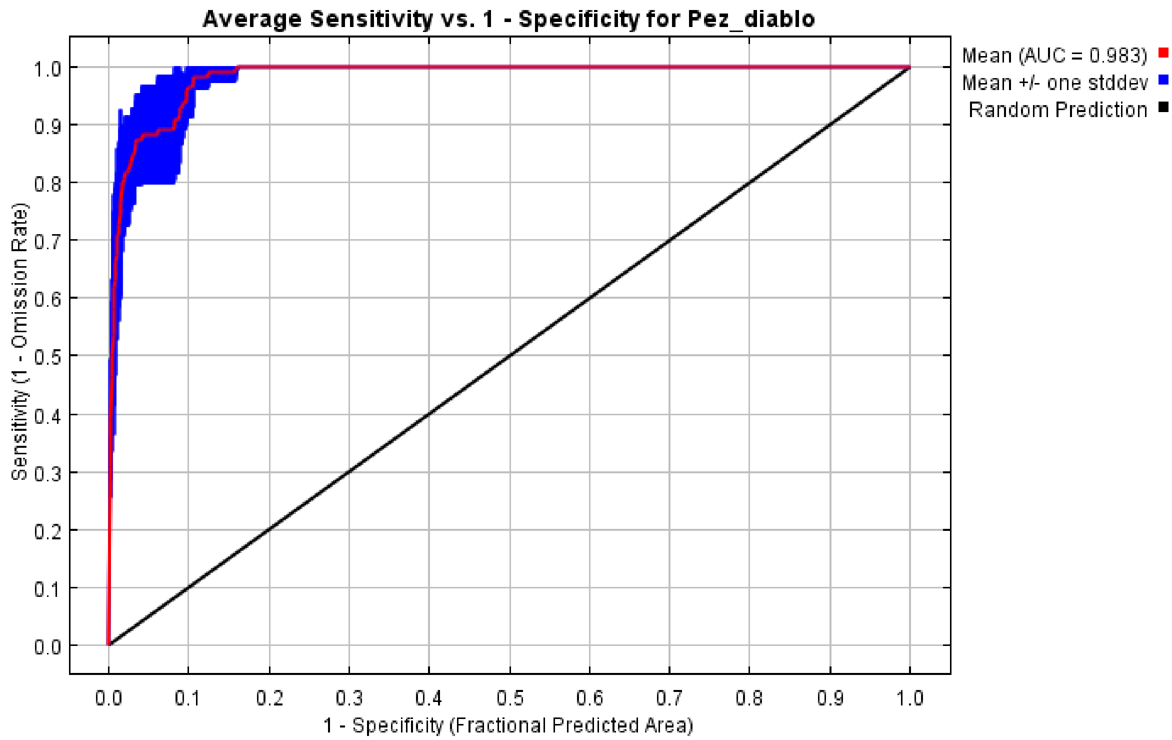


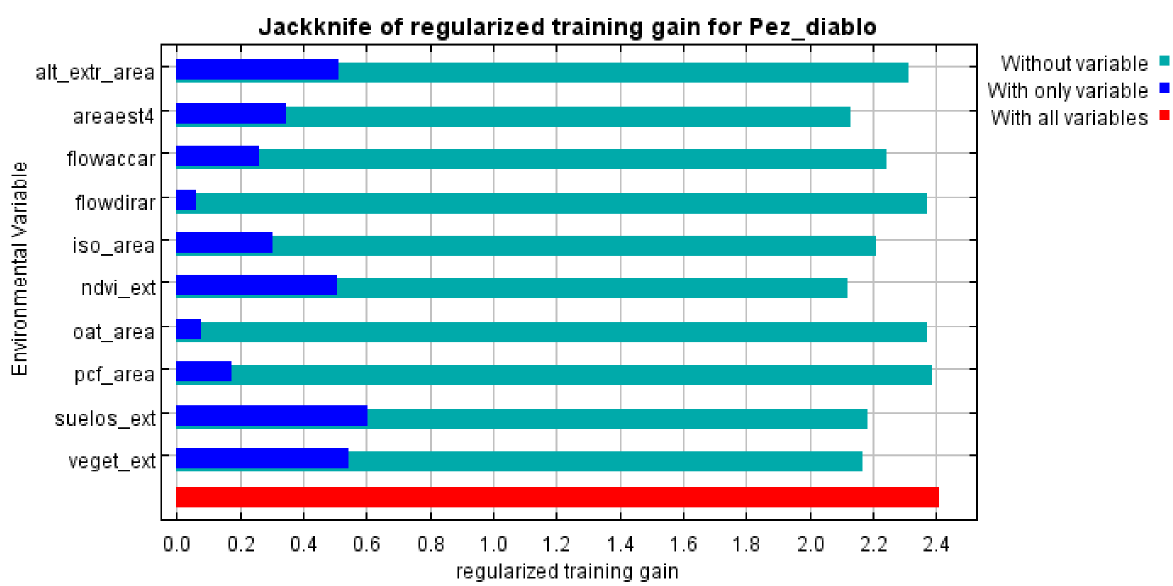
Average Sensitivity vs. 1 - Specificity for Pez_diablo
Mean (AUC = 0.957)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0



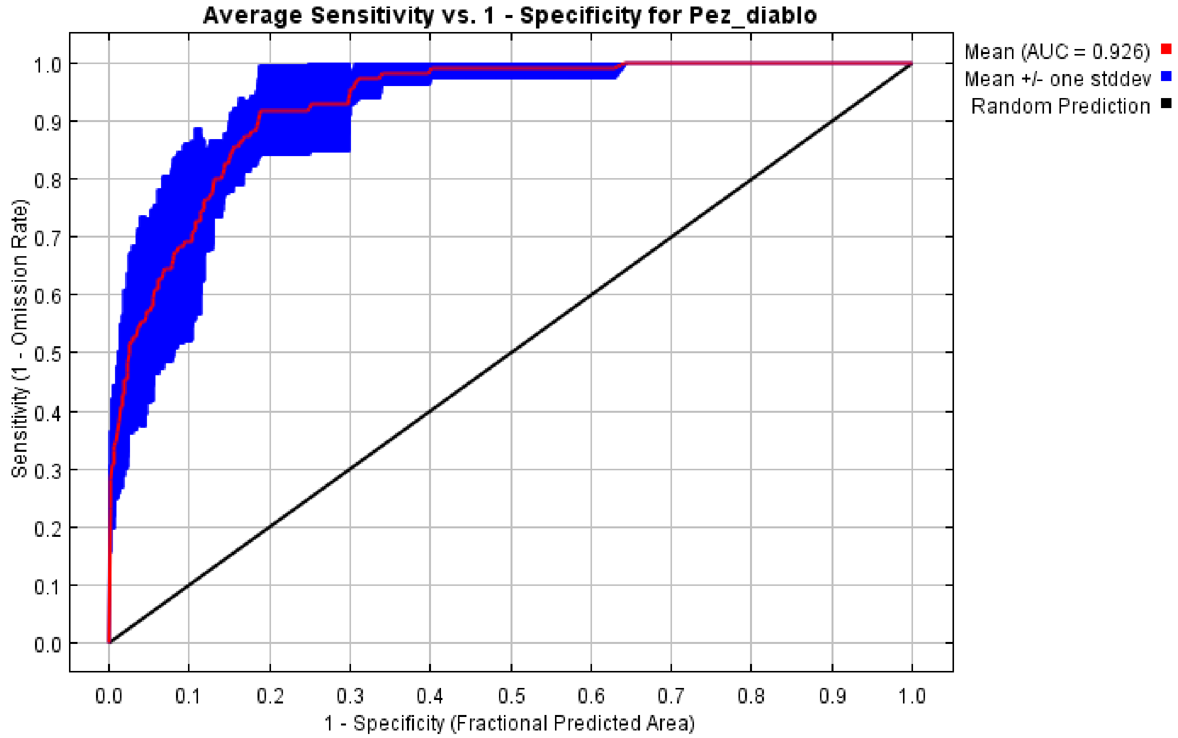
Jackknife of regularized training gain for Pez_diablo
Without variable
With only variable
With all variables
Environmental Variable
ep_area
et_area
iso_area
oat_area
odt_area
pa_area
pcc_area
pcf_area
pcll_area
pcs_area
ppll_area
pps_area
tmppc_area
tmppf_area
tpa_area
tpcc_area
tpcf_area
tpcll_area
tpcs_area
regularized training gain
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

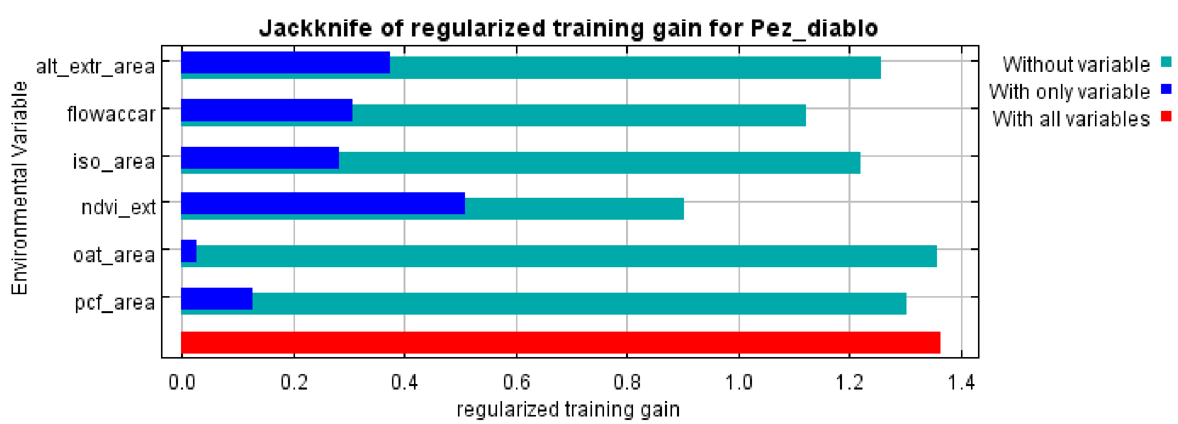
POTENTIAL 3


Average Sensitivity vs. 1 - Specificity for Pez_diablo
Mean (AUC = 0.983)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

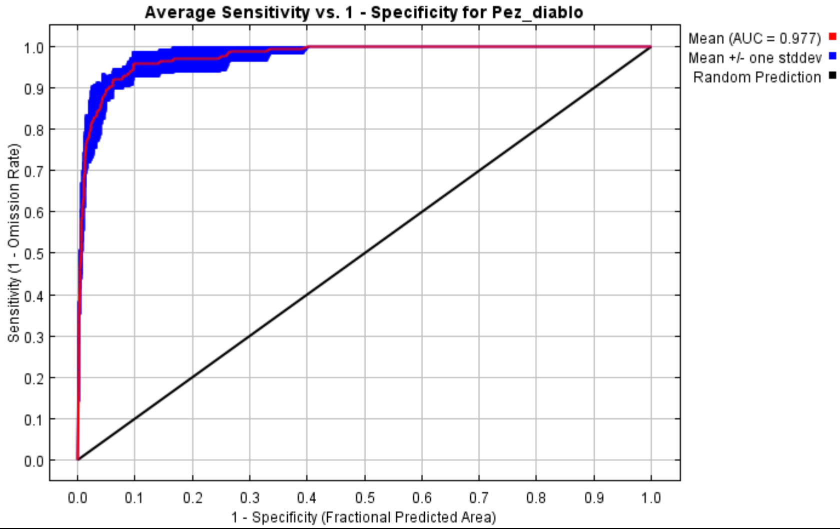

Jackknife of regularized training gain for Pez_diablo
Without variable
With only variable
With all variables
Environmental Variable
alt_extr_area
areaest4
flowaccar
flowdirar
iso_area
ndvi_ext
oat_area
pcf_area
suelos_ext
veget_ext
regularized training gain
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

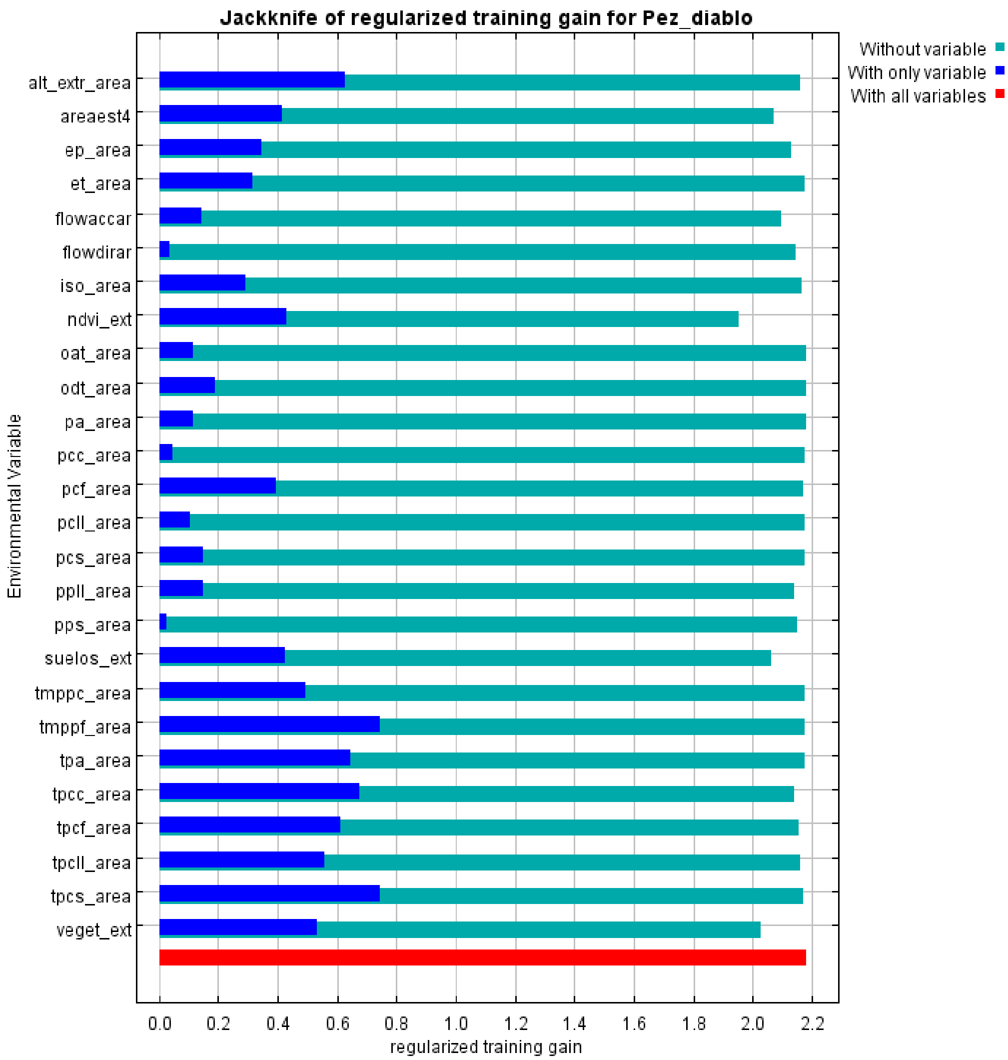
POTENTIAL 4


Average Sensitivity vs. 1 - Specificity for Pez_diablo
Mean (AUC = 0.926)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

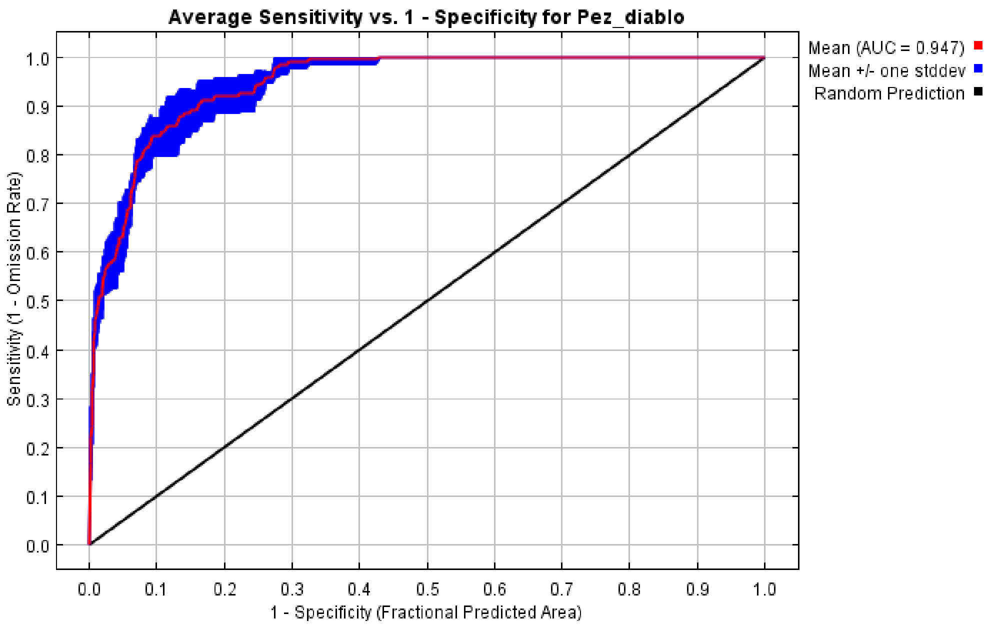

Jackknife of regularized training gain for Pez_diablo
Without variable
With only variable
With all variables
Environmental Variable
alt_extr_area
flowaccar
iso_area
ndvi_ext
oat_area
pcf_area
regularized training gain
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

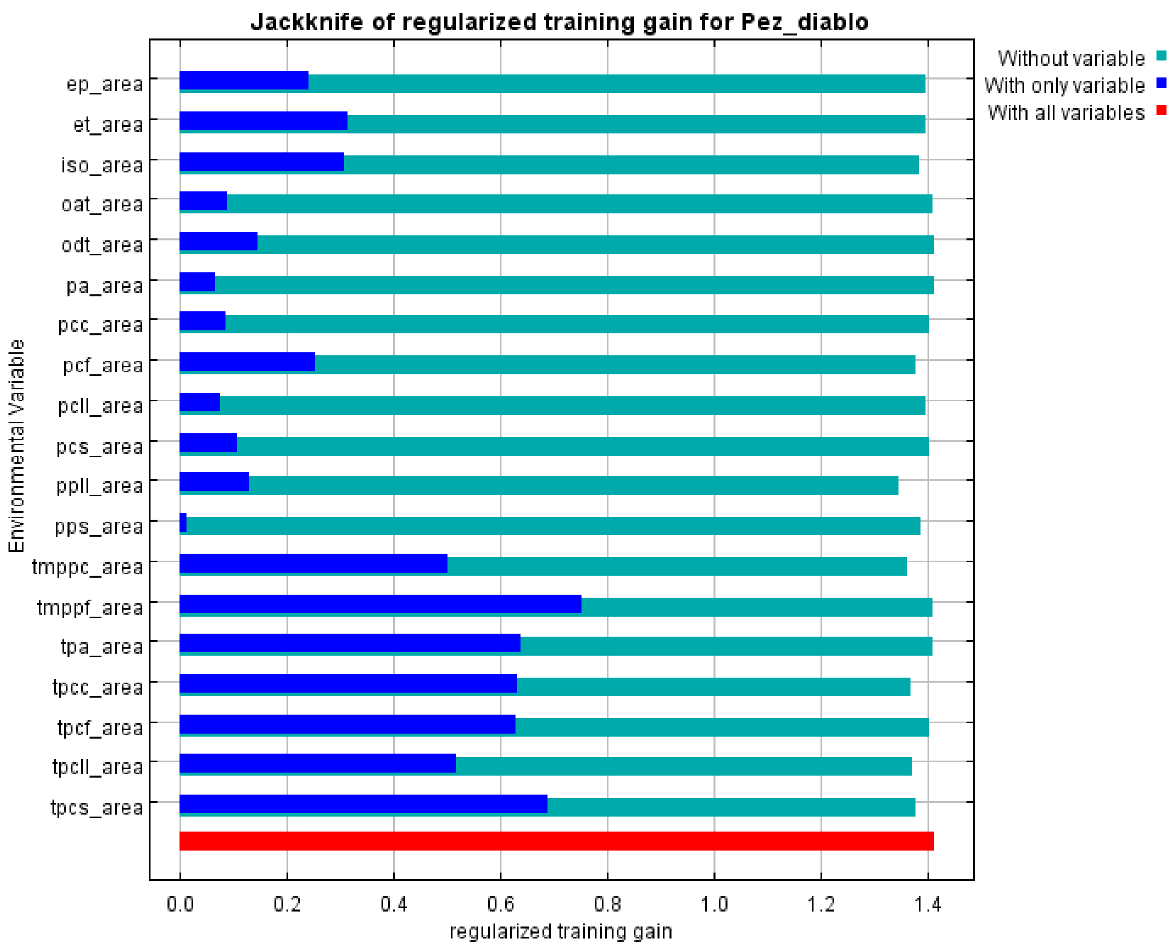
POTENTIAL 5


Average Sensitivity vs. 1 - Specificity for Pez_diablo
Mean (AUC = 0.977)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)

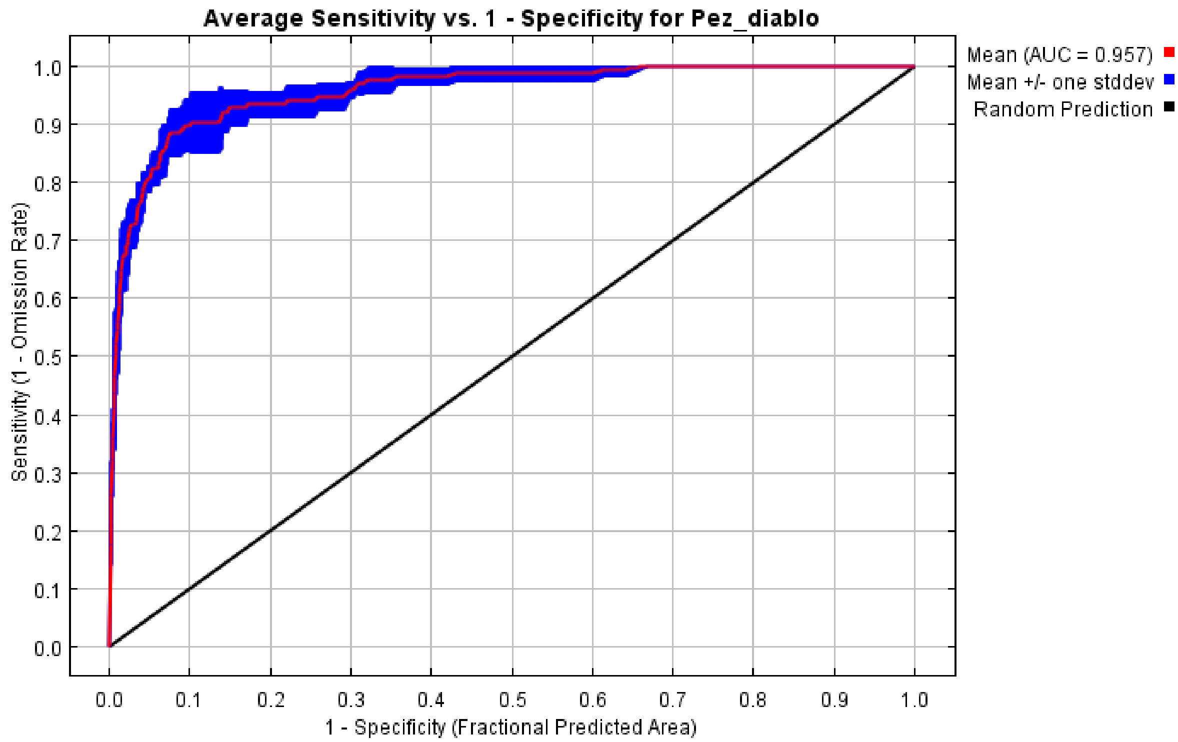

Jackknife of regularized training gain for Pez_diablo
Without variable
With only variable
With all variables
Environmental Variable
alt_extr_area
areaest4
ep_area
et_area
flowaccar
flowdirar
iso_area
ndvi_ext
oat_area
odt_area
pa_area
pcc_area
pcf_area
pcll_area
pcs_area
ppll_area
pps_area
suelos_ext
tmppc_area
tmppf_area
tpa_area
tpcc_area
tpcf_area
tpcll_area
tpcs_area
veget_ext
regularized training gain

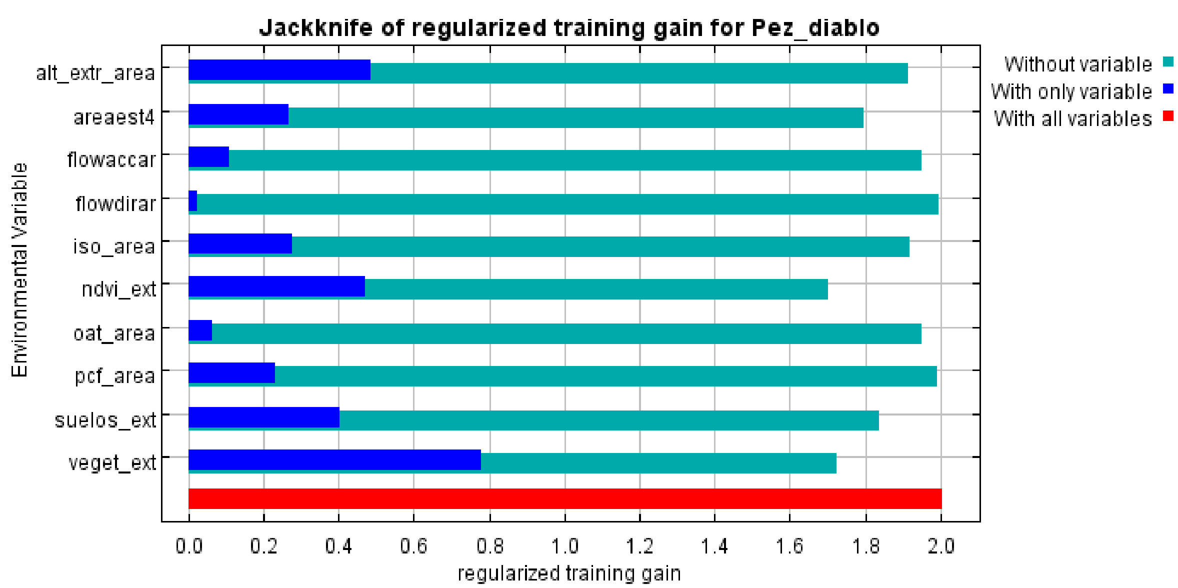
POTENTIAL 6


Average Sensitivity vs. 1 - Specificity for Pez_diablo
Mean (AUC = 0.947)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

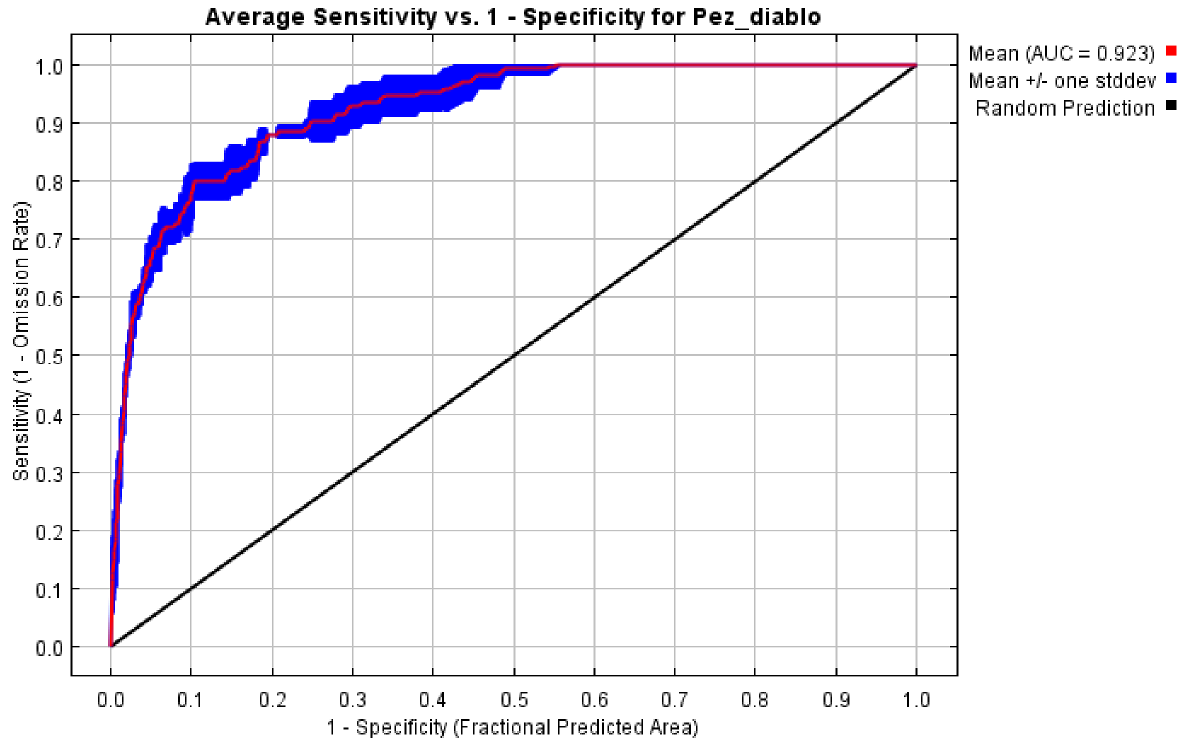

Jackknife of regularized training gain for Pez_diablo
Without variable
With only variable
With all variables
Environmental Variable
ep_area
et_area
iso_area
oat_area
odt_area
pa_area
pcc_area
pcf_area
pcll_area
pcs_area
ppll_area
pps_area
tmppc_area
tmppf_area
tpa_area
tpcc_area
tpcf_area
tpcll_area
tpcs_area
regularized training gain
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

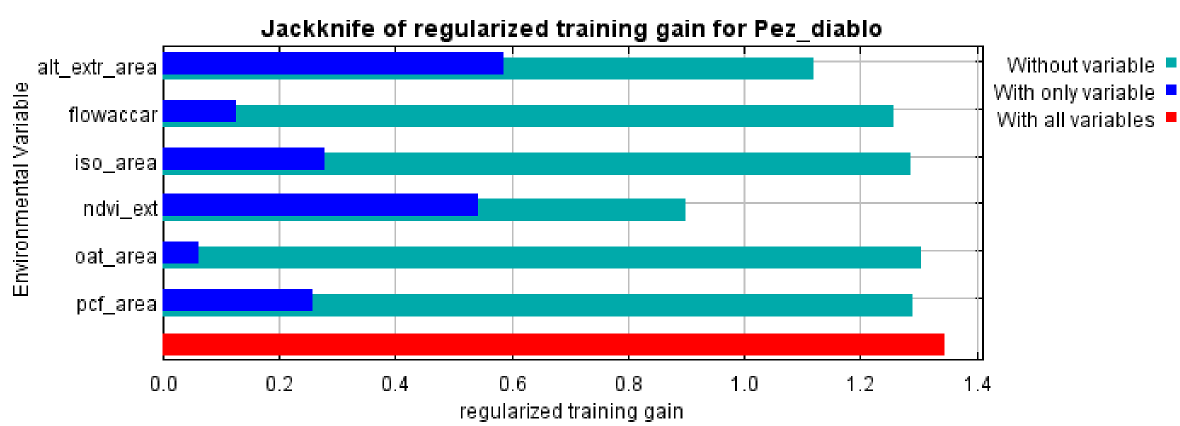
POTENTIAL 7


Average Sensitivity vs. 1 - Specificity for Pez_diablo
Mean (AUC = 0.957)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0


Jackknife of regularized training gain for Pez_diablo
Without variable
With only variable
With all variables
Environmental Variable
alt_extr_area
areaest4
flowaccar
flowdirar
iso_area
ndvi_ext
oat_area
pcf_area
suelos_ext
veget_ext
regularized training gain
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

POTENTIAL 8


Average Sensitivity vs. 1 - Specificity for Pez_diablo
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
Mean (AUC = 0.923)
Mean +/- one stddev
Random Prediction
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0


Jackknife of regularized training gain for Pez_diablo
Environmental Variable
alt_extr_area
flowaccar
iso_area
ndvi_ext
oat_area
pcf_area
regularized training gain
Without variable
With only variable
With all variables
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Appendix 10. Some common thresholds and corresponding omission rates obtained for model POTENTIAL 4 with Maxent. Validation for the model when (*p*<0.05) for at least one threshold (Pawar et al., 2007)

Cumulative threshold	Logistic threshold	Description	Fractional predicted area	Training omission rate	Test omission rate	P-value
1.000	0.015	Fixed cumulative value 1	0.632	0.000	0.000	4.023E-2
5.000	0.045	Fixed cumulative value 5	0.400	0.000	0.000	1.639E-3
10.000	0.083	Fixed cumulative value 10	0.276	0.045	0.000	1.235E-4
8.474	0.071	Minimum training presence	0.306	0.000	0.000	2.537E-4
20.692	0.170	10 percentile training presence	0.150	0.091	0.143	7.022E-5
21.597	0.178	Equal training sensitivity and specificity	0.143	0.136	0.143	5.314E-5
16.641	0.136	Maximum training sensitivity plus specificity	0.187	0.045	0.143	2.513E-4
21.664	0.178	Equal test sensitivity and specificity	0.143	0.227	0.143	5.227E-5
58.973	0.570	Maximum test sensitivity plus specificity	0.017	0.364	0.143	1.825E-10
7.167	0.061	Balance training omission, predicted area and threshold value	0.336	0.000	0.000	4.861E-4
19.264	0.157	Equate entropy of thresholded and original distributions	0.162	0.091	0.143	1.099E-4

Additional plots and results for all Maxent models can be found in the CD.