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Record and establishment of the non-native Loricariid catfish genus *Pterygoplichthys* (Siluriformes: Loricariidae) in the Coastal Plain of San Blas, Nayarit, Southeast Gulf of California, Mexico

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ABSTRACT

Record and establishment of the non-native Loricariid catfish genus *Pterygoplichthys* (Siluriformes: Loricariidae) in the Coastal Plain of San Blas, Nayarit, Southeast Gulf of California, Mexico

The establishment of non-native Loricariid catfish (Siluriformes: Loricariidae) of the genus *Pterygoplichthys*, in the Coastal Plain of San Blas, Nayarit, Southeast Gulf of California was reported. According to the morphological taxonomy and abdominal patterns, the specimens are closely related to the hybrid forms of *P. pardalis* x *P. disjunctivus*. In addition, the evidence of its establishment in the study area is presented. The individuals were captured along the Mololoa River micro-basin, on the left bank of the lower Santiago river basin, in front of Matanchen Bay in addition to one in front of the sea beach at the mouth of the Santiago River. The mean length and weight of the fish caught from 2013 to 2016 were 25.2 ± 2.2 cm and 123.2 ± 27.9 g. In the study area, uncontrolled propagation of this genus can jeopardize the diversity of fauna on the left bank of the Santiago river and the National Marsh ecosystem in the coastal plain of Nayarit, Mexico.

Key words: *Pterygoplichthys*, armored catfish, invasive species, Nayarit, México

RESUMEN

Reporte y establecimiento del bagre no-nativo Loricárido, género* Pterygoplichthys *(Siluriformes: Loricariidae), en la planicie costera de San Blas, Nayarit, Sureste del Golfo de California, México

Se reporta el establecimiento del bagre no-nativo Loricárido del género Pterygoplichthys *(Siluriformes: Loricariidae) en la planicie costera de San Blas, Nayarit, Sureste del Golfo de California, México. La taxonomía morfológica y los patrones abdominales revelaron que los especímenes están estrechamente relacionados con formas híbridas de* P. pardalis *x* P. disjunctivus*. Además, se presenta la evidencia de su establecimiento en el área de estudio. Los individuos fueron capturados a lo largo de una red de arroyos, canales, ríos y lagunas interconectados y constituidos por la microcuenca del río Mololoa, margen izquierda de la cuenca baja del río Santiago, frente a la bahía de Matanchen y desembocadura del río Santiago. La longitud y el peso promedio de los peces capturados entre 2013 y 2016 fueron de 25.2 ± 2.2 cm y 123.2 ± 27.9 g. Sin embargo, la propagación incontrolada de este género en el área de estudio puede ser una amenaza para la diversidad de la fauna de la cuenca baja del río Grande de Santiago y el ecosistema Marismas Nacionales en la llanura costera de Nayarit, México.*

Palabras clave: Pterygoplichthys*, bagre armado, especies invasoras, Nayarit, México*

INTRODUCTION

The utilization of fish for aquarium purposes has contributed significantly to the spread of organisms with invasive potential (Capps & Flecker, 2013). The loricariids (*Pterygoplichthys* spp.), known as plecos, sailfin catfish or armored catfish, are native to South America, Costa Rica, Panama, and the Amazon Basin (Orfinger & Goodding, 2018). Their territorial expansion worldwide began in the middle of the twentieth century (Ayala-Pérez *et al.*, 2014). It is noteworthy that Loricariid catfish have established themselves as invasive species in various regions of the world, including Thailand (Chaichana & Jongphadungkiet, 2012), Singapore, the Philippines, Indonesia, Malaysia, Vietnam, (Barba *et al.*, 2014), Africa (Hoover *et al.*, 2014), EE. UU (Hawaii), México, Japan, India, and Israel (Bijukumar *et al.*, 2015; Muralidharan *et al.*, 2015; Wakida-Kusunoki *et al.*, 2016). In Mexico, the two species that are particularly recognized are: *Pterygoplichthys pardalis* and *P. disjunctivus* (Mendoza *et al.*, 2009; Wakida-Kusunoki *et al.*, 2016). However, genetic evidence suggests that *P. disjunctives* represents a synonym for *P. pardalis* (Jumawan *et al.*, 2011; Wu *et al.*, 2011; Yu & Quilang, 2014).

The territorial species of *Pterygoplichthys* have a high reproduction rate and parental care. Additionally, they are nocturnal and highly resistant to desiccation. These species can withstand varying conditions of water quality. Their hardened external morphology and spines allow them to evade predators, which, in turn, makes it possible for them to colonize new habitats. *Pterygoplichthys* has been classified as a genus with high invasive potential (Gibbs *et al.*, 2008, Simonović *et al.*, 2010, Capps & Flecker, 2013, Zworykin & Budaev, 2013, Bijukumar *et al.*, 2015). Popula-

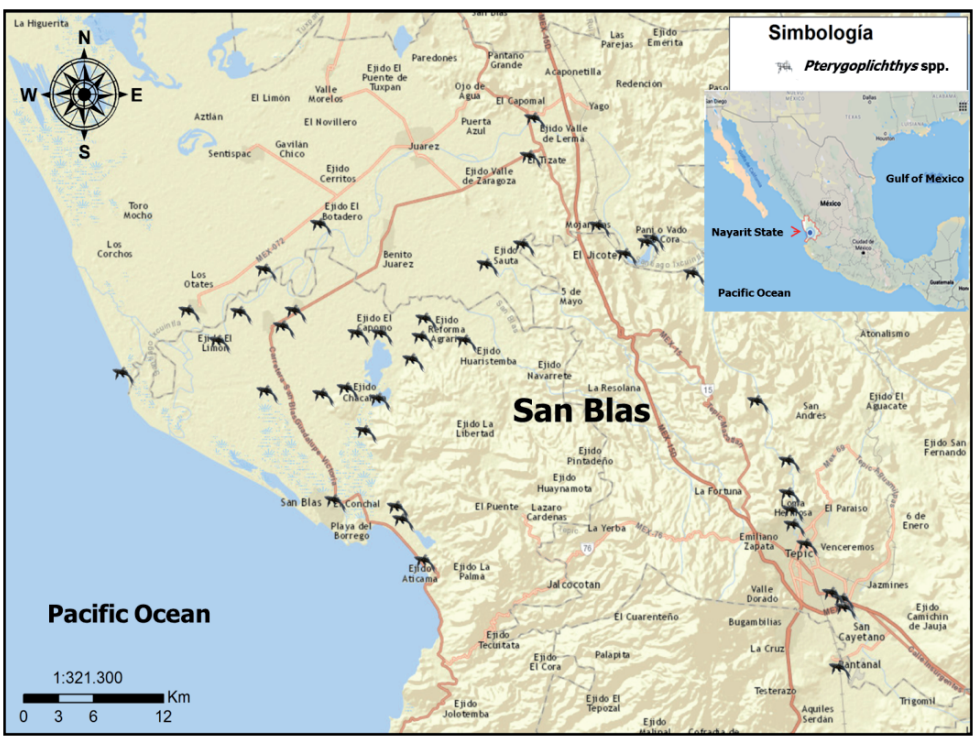

Figure 1. Map of the study area in San Blas, Nayarit, Mexico, shows the lower basin of the Río Grande de Santiago. Fish figures indicate the sites where Amazon sailfin catfish of genus *Pterygoplichthys* were captured. *Mapa de la zona de estudio en San Blas, Nayarit, México, se muestra la cuenca baja del Río Grande de Santiago. Las figuras de los peces indican los sitios donde fueron capturados individuos de Amazon sailfin catfish del género* Pterygoplichthys.

tions of this genus have proliferated in natural areas of Mexico, which has caused a sudden increase in the abundance of juveniles within new environments (Wakida-Kusunoki *et al.*, 2007; Mendoza *et al.*, 2009). In 1995, the first report of a wild population of Loricariid catfish genus *Pterygoplichthys* was recorded in the Mezcala River, Guerrero (Guzmán & Barragán, 1997). Three years later, some samples were reportedly found at the Adolfo López Mateos dam "El Infernillo" in the state of Michoacán (Ayala-Pérez *et al.*, 2014). Since then, reports have emerged for the states of Morelos (Mendoza *et al.*, 2009), Campeche (Wakida-Kusunoki & Amador-del-Angel, 2011), Chiapas (Capps & Flecker, 2013), Tabasco (Barba *et al.*, 2014; Ríos-Muñoz, 2015) and Sinaloa (Amezcua-Martínez, 2014). Against this backdrop, the aim of the present study is to present the first record and establishment of the genus *Pterygoplichthys* spp., in freshwater and brackish water of the Coastal Plain of San Blas Nayarit, southeast Gulf of California, Mexico.

MATERIALS AND METHODS

The armored catfish were collected from the lower basin of the Grande de Santiago River (mainstream and adjacent channels) as well as in the lagoon-estuarine system and wetlands of San Blas (Fig. 1), Nayarit (76054' – 76058' E and 8044' – 8049' N), using cast net (3 m high, 1.27 cm mesh size and 3 m wide), during various time periods (night and day) in May 2013, March 2014, February 2015, and October 2016. During the study period (2013 to 2016), a total of 400 organisms were collected, which included 220 females and 180 males; 60 fish were fixed with 10 % formaldehyde, whereas the rest were released into water body where they were captured. Pro2030 Dissolved Oxygen, Conductivity, Salinity (YSI Instrument) and pH (Groline, Model: HI 98118) were used for the water quality variables.

Fish were weighed to the nearest ± 0.1 g with a digital scale. In addition, morphometric measurements, such as total length (TL), standard length (SL), body height (BH) and head height (HH), were taken on their left side to the nearest 0.1 mm, with digital calipers. The length-weight

Figure 2. Left side view of *Pterygoplichthys* captured in the study area. *Vista lateral izquierda de* Pterygoplichthys *capturado en el área de estudio.*

ratio (LWR) was determined using the following equation: $W = aL^b$ were W denotes the total weight (g), L represents the total length (cm) (Froese *et al.*, 2011; Le Cren, 1951) *"a"* signifies the intersection, and *"b"* is the regression slope, which, in turn represents the type of growth. If $b = 3$, growth is considered isometric. In contrast, the growth is considered allometric when $b \neq 3$ (Ricker 1975). This can be negative ($b < 3$) when fish grow more in length, or positive ($b > 3$) when fish grow more in weight (Froese, 2006). In order to estimate parameter *"a"* and *"b"*, a timeline of the potential model on aggregate error was considered $(\log_e (wi) = \log_e (a) + b \log_e (Li) + ei)$ with a view to stabilizing the variables and obtaining a better fit of the model (Ogle, 2013), t-Student test (95 % CI) was used to infer the type of growth by parameter b (Sokal & Rohlf, 1995). Analyses were then performed using the R programming language with the statistical routines expounded by Ogle (2013). The condition factor (CF) for the species that presented allometric growth was calculated.

$$CF = \frac{W}{aL^b}$$

(Le Cren, 1951; Froese, 2006) which was estimated using an excel spreadsheet.

Depending on the size of the organisms, the gender was determined by the morphotype char-

acters and direct observation of the gonads. The fish caught were identified using the keys of Armbruster (2001, 2004) and Page and Robins (2006). In addition, digital camera was used to make a photographic catalog; the images show color variations in the ventral marks. Some reference individuals were also included in the ichthyology collection at the National School of Fishing Engineering Academic Unit (ENIP-CI) in San Blas, Nayarit, Mexico.

In addition to using analysis of variance (ANOVA) to determine the differences in morphometric characteristics and body weight of the entire population of *Pterygoplichthys*, the Tukey test was used to determine the mean difference (Zar, 1996). In particular, the ANCOVA analysis was used to determine the differences in slopes of the female and male captured (Zar, 1996).

RESULTS

The morphometric characteristics and abdominal patterns (based on coalescence and the arrangement of limited spots) of collected organisms reveal the presence of specimens of genus *Pterygoplichthys* in the study area (Fig. 2). The organisms collected presented a wide variation, reflecting in the presence of *Pterygoplichthys pardalis* (Castelnau, 1855), *P. disjunctivus* (Weber, 1991) as well as the inter-grade morphological forms or hybrid (*P. pardalis* x *P. disjunctivus*) (Fig. 3). *P. pardalis* presented discrete black spots on the ventral side of the body (Fig. 3b). Thereafter, the hybrids were joined together, which resulted in the formation of vermiculation (Fig. 3 a,c-j).

A total of 400 fishes were caught from rivers, streams, and canals from May 2013 to October 2016. The weight range of these fishes captured was 22 to 324 g (Table 1). The specimens of *Pterygoplichthys* were captured along the Mololoa River micro-basin, on the left bank of the lower Santiago river basin, in front of Matanchen Bay and in front of the sea beach at the mouth of the Santiago River (Fig. 1). During the study period, the range of water quality variables were temperature (18-29 °C), salinity (0-10 g/L), pH (7.6-8.0), and dissolved oxygen (4.4-6.3 mg/L). The coexistence of the two morphological forms was found in the majority of localities sampled. This work indicates that the dispersion of the genus continues through the Santiago River basin.

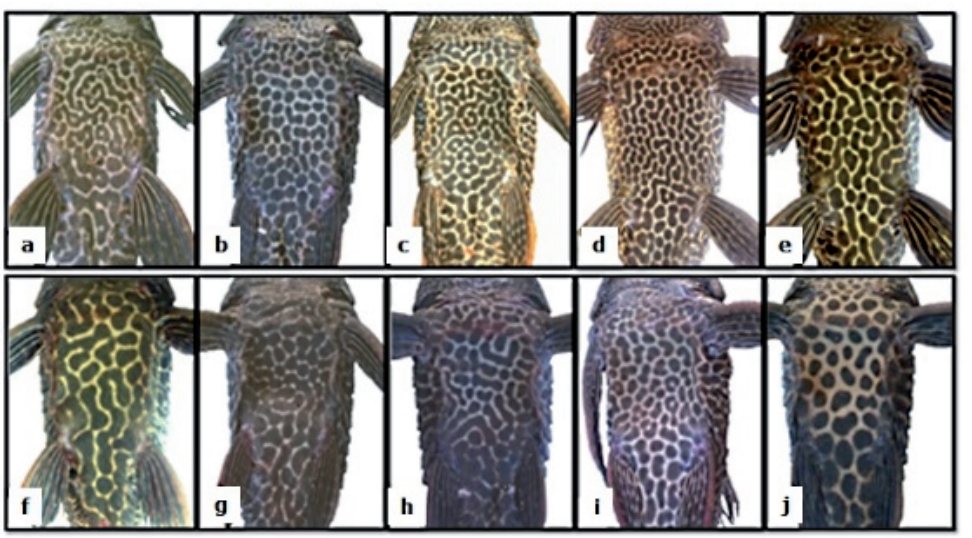

Figure 3. Intermediate ventral view of abdominal patterns of adults of *P. pardalis* and *P. disjunctivus* x *P. pardalis*. Abdominal view of hybrids (a,c-j), *P. pardalis* presented discrete black spots on the ventral side of the body (b). *Vista ventral intermedia de patrones abdominales de adultos de* P. pardalis *and* P. disjunctivus *x* P. pardalis*. Vista abdominal de híbridos (a, c-j),* P. pardalis *presentaron puntos negros discretos en el lado ventral del cuerpo (b).*

Table 1. Morphometric characteristics (cm) and body weight (g) of *Pterygoplichthys*. Mean (±SD). *Características morfométricas (cm) y peso del cuerpo (g) de* Pterygoplichthys. *Media (± DS).*

Characteristics	2013			2014			2015			2016		
	Range	Mean	Total	Range	Mean	Total	Range	Mean	Total	Range	Mean	Total
Number of Organisms			22			48			155		175	400
Total length (TL)	17.0-28.0	22.5±3.9[b]		23.5-28.0	26.0±1.4[a]		14.0-33.0	26.7±3.1[a]		18.0-32.1	27.1±2.7[a]	
Standard length (SL)	17.0-21.0	18.9±1.9[a]		18.0-21.0	19.38±0.9[a]		10.0-30.0	18.48±4.1[a]		13.5-26.0	19.2±2.9[a]	
Abdominal length (AL)	4.0-7.0	5.7±1.2[b]		5.0-7.0	5.8±0.9[b]		1.5-6.5	4.76±0.7[b]		1.5-9.0	7.35±0.5[a]	
Head length (HL)	3.5-6.5	5.0±1.1[a]		4.0-7.0	5.2±1.2[a]		1.0-5.0	3.99±0.5[b]		6.0-8.0	6.6±0.6[a]	
Weight (W)	26.9-180	92.7±51.9[b]		114-180	140.3±16.9[a]		22-210	138.3±35.5[a]		50-324	148.1±42.8[a]	
Condition Factor (CF)	1.78-2.07	1.94[a]		1.77-2.01	1.82[a]		1.94-2.28	2.19[a]		1.89-2.15	2.09[a]	

The L *vs.* W relation of the entire population of organisms collected shows a potential model with an allometric coefficient of 2.6798 ($r^2 = 0.9044$, $p < 0.05$) (Fig. 4). After analyzing the LWR of the organisms captured in 2013, a value of $b \geq 3$ ($r^2 = 0.933$, $b = 3.061$) was recorded, indicating a positive allometric growth ($p < 0.05$). Meanwhile, a value of $b \leq 3$ ($r^2 = 0.88$, 0.87, 0.83; $b = 2.09$, 2.39 and 2.60, respectively) was recorded with regard to the analysis of the organisms captured from 2014, 2015, which indicated a negative allometric growth ($p < 0.05$). The mean size of females and males was 26.09 ± 1.74 cm, 27.08 ± 1.65 cm and 136.25 ± 21.88 g, 139.43 ± 18.48 g, respectively. According to ANCOVA ($p < 0.05$), no significant differences were found between the allometric growth of males $W = 0.01847\ (L)^{2.21}$ and females $W = 0.2254\ (L)^{2.19}$.

DISCUSSION

In general, the captured specimens experienced slight variations in the range given by Weber (1992). Initially, the identification of organisms of *P. pardalis* and *P. disjunctivus* within the genus *Pterygoplichthys* was rendered complicated due to the involvement of four closely related species such as *P. anisitsi*, *P. multiradiatus*, *P. pardalis* and *P. disjunctivus* that have been separated on the basis of their abdominal patterns and morphology (Nico & Martin, 2001; Nico *et al.*, 2012), and mtDNA sequences (Wu *et al.*, 2011). However, there has been lack of clarity in establishing the identity of the invaded species in other regions (Bijukumar *et al.*, 2015). Therefore, it can be surmised that the organisms introduced in other regions as well as Mexico can be classified as hybrids *P. disjunctivus* x *P. pardalis* (Wu *et al.*, 2011).

The size range of captured *Pterygoplichthys*

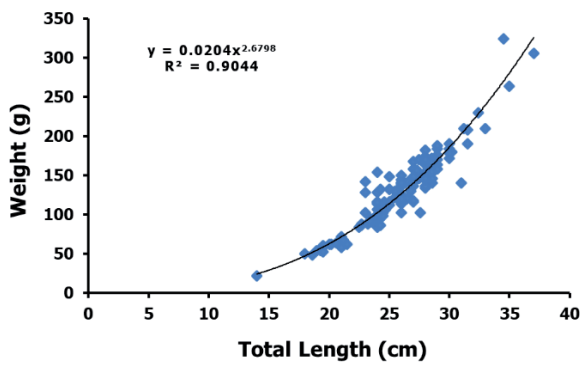

Figure 4. Total length-body weight linear regression of all population of the genus *Pterygoplichthys* from the Coastal Plain of San Blas, Nayarit, Mexico. *Regresión lineal de la longitud total y el peso corporal de todas las poblaciones del género* Pterygoplichthys *de la llanura costera de San Blas, Nayarit, México.*

was 10 to 30 cm SL, with a mean of 18.48 cm. These fish could live up to 5.25 years and grow up to 51.5 cm of SL, with a rapid growth rate of approximately 10 cm per year (Gibbs *et al.*, 2008). The length-weight recorded a negative allometric growth of *Pterygoplichthys*, which was consistent with the reports of Rueda-Jasso *et al.* (2013), Wei *et al.* (2017) and Hussan *et al.* (2019). This indicates that fish tend to lose weight and be fewer with greater length. The value of $CF \geq 1$ is indicative of the fact that the population is healthy and that the translocation of *Pterygoplichthys* has been favored by what has allowed it to successfully colonize its new environment in the coastal plain of San Blas, Nayarit, southeast of the Gulf of California, Mexico (Le Cren, 1951).

The majority of organisms captured exhibited a variation of intermediate coloration, thus indicating hybridization (Hoover *et al.*, 2014; Bijukumar *et al.*, 2015). This may indicate that the initial invasion has had a long time. In addition, the collections of recent years have shown that many of these organisms have had intermediate morphologies (Fig. 3), reinforcing the theory of the existence of early hybridization event (Wu *et al.*, 2011; Godwin *et al.*, 2016). Those hybrid organisms have also been known to increase their adaptation to the study area's environment for better invasion (Seehausen *et al.*, 2008; Karthick *et al.*, 2017). The adaptation of this group to salinities of 10 g/L has been demonstrated by capturing organisms in the canals and estuaries of the Municipality of San Blas every year. This, in turn, has been congruent with the maximum tolerance levels that have been recorded for the species of 12 g/L (Brion et al., 2013; Kumar *et al.*, 2018) with 100 % survival. The presence of the genus study area could be attributed to the accidental escape of an ornamental fish farm located in the valley of Matatipac, Armadillo locality after Hurricane Kenna in 2002 and organisms from the Grande de Santiago river which spread across to lower parts of the basin, as well as to varying mechanisms distributed in the lentic and lotic systems of freshwater and brackish (up to 10 g/L salinity) water coastal plain of the municipality of San Blas, Nayarit, Mexico.

The dispersion of the non-native Loricariid catfish in the Coastal Plain of San Blas, Nayarit, has been facilitated by the "El Jileño" bypass on the Santiago river supplying the irrigation canals to the left and right bank of the Santiago river along with the prevailing interconnectivity hydrological in the area, primarily during the rainy seasons, thus demonstrating its adaptation different habitats of freshwater and brackish water (Capps *et al.*, 2011; Capps & Flecker, 2013 Jones *et al.*, 2013).

Since the emergence of non-native Loricariid catfish in the area, catches of native species have declined significantly. Contrastingly, there has been an increase in the frequency and volume of the fish catch of the genus *Pterygoplichthys*. This has already been reported for several Mexican Pacific states such as Guerrero, Michoacán, and Sinaloa with regard to the decline in tilapia catches (Mendoza *et al.*, 2009; Amezcua-Martinez, 2014).

The ecological effects of *Pterygoplichthy* in the study area have not been determined in particular. However, an increase in populations of non-native Loricariid catfish has been observed over time along with a decrease in local fisheries primarily from *Macrobrachium* spp. such as what has been reported in the Southeast of Mexico (Wakida-Kusunoki *et al.*, 2008). The results obtained in this study suggest that the genus *Pterygoplichthys* can be totally considered an invasive taxon, category E (Jones *et al.*, 2011), with individuals dispersing, surviving, and reproducing in multiple sites across a greater or lesser spectrum of habitats and extent of occurrence. As reported, the effect of Loricariid catfish on the environment include the following: drastic modification of nutrient regimes and biogeochemical cycling, siltation, and erosion caused by burrowing males, with the effect on biota as a vector for nonnative parasites acting as egg predators of native fishes and resulting in declining fish food resources (Orfinger & Goodding, 2018).

Juvenile stages of *Pterygoplichthys* have assumed significance for the settlement and recruitment in the study area (Sheaves *et al.*, 2006), due to the type of habitat that comprises of a network of drainage channels and lagoons with adequate conditions for feeding and reproduction of *Pterygoplichthys* in such a manner that the settlement and recruitment have been related in the same habitat where adults are found, as report-

ed for other fish (Garcia-Rubies & Macpherson, 1995). However, more detailed studies were required in the lower basin of the Grande de Santiago River and San Blas River in order to determine the temporal and spatial variation in settlement and recruitment of *Pterygoplichthys* in the study area's canal and lagoon system.

This work shows that the dispersion of Loricariidae catfish genus *Pterygoplichthys* continues in the Mexican Pacific coast, and as reported by Wakida-Kusunoki and Amador-Del Angel (2008), in the coastal area of the Gulf of Mexico. Therefore, control and eradication is urgently necessitated. Finally, the species of the genus *Pterygoplichthy* have not been considered in the management plans of the Protected Natural Area adjacent to the study area called "Marismas Nacionales-Nayarit" since the studied species will significantly endanger the native biodiversity of the Biosphere Reserve. In general, the presence of juveniles, adults, and mature females in several areas of the coastal plain of San Blas Nayarit indicates that the species is already well-established in the region. This, in turn, is endangering local species and the equilibrium of the ecosystem.

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