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Distribution and Habitat Suitability of Andean Climbing Catfish in the Napo River Basin, Ecuador

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Abstract

Astroblepidae face numerous threats in Ecuador, and their range is thought to be decreasing in most basins due to urban development, agriculture, oil and mineral extraction, dams, and introduction of exotic species. In the Napo River Basin, one of the largest and most-diverse river basins in Ecuador, *Astroblepus vaillanti* is also potentially being displaced by rainbow trout (*Onchorynchus mykiss*) introductions at higher altitudes, yet no published information exists on the habitat requirements and distribution of the species. In this study, we developed species–habitat relationships for a suite of physico-chemical variables and compared abundances of *A. vaillanti* in streams heavily impacted by agriculture and less impacted streams. Interestingly, we found significantly higher abundances of *A. vaillanti* in heavily impacted streams. We also found that *A. vaillanti* abundance was positively related to stream temperature, whereas the inverse was true for rainbow trout. Our study highlights the need for further study to understand the habitat requirements and diet of *A. vaillanti* as well as the impacts of rainbow trout on the species to inform conservation efforts of the species.

Keywords

Astroblepus spp., habitat suitability, species conservation, species distribution, species invasion, land use

Introduction

The Andean catfish (*Astroblepus* a genus of catfish [order Siluriformes]) inhabits high-gradient streams and rivers of the tropical Andes (Maldonado-Ocampo et al., 2005; Román-Valencia, 2001). The family Astroblepidae contains 23 known species (Barriga, 2012) in Ecuador distributed along an altitudinal gradient from approximately 500 m to 3,500 m asl. Unfortunately, limited information exists on the distribution, conservation status, population dynamics, and habitat preferences for the majority of these species. Astroblepidae face numerous threats in Ecuador, and their range is thought to be decreasing in most basins due to urban development, agriculture, oil and mineral extraction, dams, and introduction of exotic species (Mena et al., 2006; Potes, 2010). In the Napo River Basin, one of the largest and most diverse river basins in Ecuador (Lessmann et al., 2016), *Astroblepus* spp. are also displaced by the introduced rainbow trout (*Onchorynchus mykiss*) in the higher elevations.

Rainbow trout have been introduced in many high-altitude tropical Andean streams and can impact trophic structure, aquatic invertebrates, and fish communities (Flecker, 1992). *Astroblepus* spp. were historically abundant in highland streams throughout the tropical Andes, including the Napo River Basin, up to elevations of 3,500 m (Barriga, 2012). However, since the introduction of rainbow trout into the region (Vimos, Encalada, Ríos-Touma, Suárez, & Prat, 2015), *Astroblepus* spp. are thought to have been displaced to lower elevations and are rarely, if ever, found in sympatry with trout. Few, if any, published studies have addressed this displacement by nonnative trout.

As human development and introductions of rainbow trout in the Napo River Basin increases, the long-term

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population viability and conservation status of *Astroblepus* remains unknown. To our knowledge, no published data exist for the on the abundance and habitat suitability of *Astroblepus vaillanti*, the most common species of Astroblepus in the Napo River Basin and an endemic species to Ecuador (Barriga, 2012). The goal of this study was to determine: (a) the distribution of *A. vaillanti* along an elevational gradient in the upper Napo River Basin, (b) whether *A. vaillanti* are found in sympatry with rainbow trout, and (c) develop habitat suitability models for *A. vaillanti* and determine which environmental factors might be most limiting to population abundance.

Methods

To estimate fish abundance and biomass, we conducted multiple-pass backpack electrofishing (FEG 1500; EFKO-Elektrofi schfanggeräte, Leutkirch, Germany) depletion population estimates during February and March 2015 on 12 study streams (Table 1, Figure 1). The surveyed stream section was isolated using blocking seines or natural features (shallow riffles, cascades) to approximate a closed population compatible with a depletion estimate. Sites selected for electrofishing were representative of both the habitat and were stratified into three altitudinal zones; high ($\geq$2,800 m), intermediate (2,000–2,799 m), and low ($\leq$1,999 m). Upon capture, we weighed and measured each fish (Figure 2). To examine the effect of land use, we further stratified our sites into agricultural and less disturbed sites. Six streams were in predominantly agricultural drainages and six were in undeveloped or less disturbed drainages (Figure 3).

We evaluated the influence of physicochemical (conductivity, dissolved oxygen, temperature, pH, ammonium [NH_4], and soluble reactive phosphate [SRP] concentrations), altitude, stream width, and habitat parameters Riparian Forest Quality Index (QBR) and Index of Fluvial Habitat (IHF) on *A. vaillanti* abundance (Acosta, Ríos, Rieradevall, & Prat, 2009). Physicochemical parameters were measured a minimum of three times using an YSI 550 multiprobe meter, then we used the average for analysis. Altitude was measured using a Garmin Dakota 20 GPS unit, accurate to within 3 m. Stream width was recorded as wetted width using a field tape measure. NH_4 was quantified using standard fluorometric methods (Taylor et al., 2007). We determined SRP concentrations based on the reaction of the orthophosphate ion (PO_4^{-3}) with ammonium molybdate and antimony potassium tartrate in an acid medium (Stainton, Capel, & Armstrong, 1977).

We used a modified Riparian Forest Quality (QBR) index to assess the habitat quality of the riparian zone in our study streams (Munné, Prat, Solà, Bonada, & Rieradevall, 2003). The four main aspects of the QBR index are the following: total vegetation cover, vegetation cover structure, cover quality, and channel alterations. We used a modified Index of Fluvial Habitat (IHF; Pardo et al., 2002) adapted for the assessment of fluvial habitat in tropical Andean rivers. The method aims to characterize physical habitats (heterogeneity) and relate them to biological indicators.

We used generalized additive models (GAMs; Hastie & Tiburani, 1990) to determine which environmental factors might be most limiting to population abundance. GAMs provide greater flexibility for modeling fish–

Table 1. Mean Physical, Chemical, and Habitat Parameters for the 12 Study Streams in the Napo River Basin.

Site	Land use	NH4	SRP	Elev.	QBR	IHF	pH	DO	Cond.	Temp.	Width
1	AG	23	8	1,789	20	63	8	7	210	17	1.1
2	AG	25	13	2,006	21	46	8	7	138	17	0.5
3	AG	13	4	1,727	10	32	7	8	54	16	1.3
4	AG	13	4	1,700	10	54	8	8	83	18	0.75
5	LD	14	3	2,257	40	67	7	8	31	15	2.01
6	LD	23	3	2,115	80	73	8	8	108	15	2.04
7	AG	25	6	2,184	30	72	9	9	126	15	0.55
8	AG	12	5	1,877	0	49	7	9	106	16	0.75
9	LD	16	4	2,880	100	68	8	8	20	11	5
10	LD	1	2	3,863	25	70	6	10	45	9	1.12
11	LD	7	2	3,487	75	46	7	9	42	9	2.07
12	LD	4	1	3,487	80	71	8	8	89	9	2.5

Note. Land-use categories where AG = agricultural stream, LD = less disturbed stream; NH4 = ammonium concentration (μg m^{-2}); SRP = soluble reactive phosphorus (μg m^{-2}); QBR = riparian habitat quality; IHF = Index of Fluvial Habitat; DO = dissolved oxygen (mg L^{-1}); Cond. = specific conductivity (μs cm^{-1}); Width = mean wetted stream width (m).

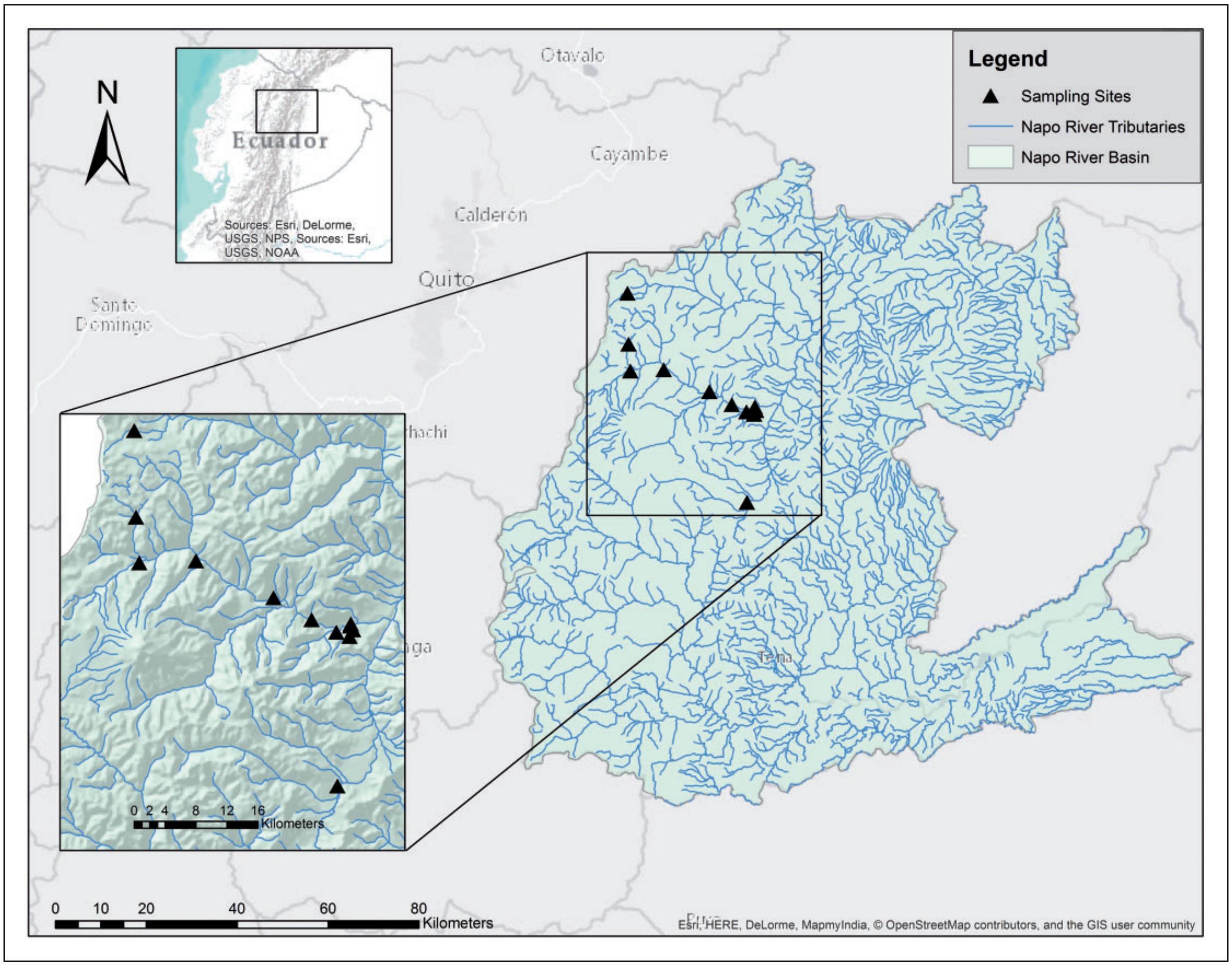

Figure 1. Overview map of study area and study sites (inset) in the Napo River Basin, Ecuador.

Figure 2. Photograph of *Astroblepus vaillanti* collected in this study. (Preliminary genetic analyses indicate that there are potentially two species in addition to *A. vaillanti* found within these sites, though the genetic work for these specimens is underway.)

habitat relationships than general linear models because the distribution of the dependent variable can be nonnormal. In addition, variables do not have to be continuous, allowing for quantitative prediction of variable thresholds in habitat selection (Jowett & Davey, 2007).

To test for differences in *A. vaillanti* abundance within agricultural and less disturbed drainages and in the presence of rainbow trout, we used a multifactor additive analysis of variance, where we tested for interactions between altitude and land use and rainbow trout presence and included additive terms for the additional habitat and physicochemical variables. Finally, we used a Leslie–Delury binomial model to estimate abundance from depletion data. We used QQ plots and a Shapiro–Wilk test to visually and analytically test, respectively, whether our sample came from a normally distributed population. Where data were not bivariate normal we used appropriate log transformations. All statistical analyses were conducted in Program R version 3.1.1.

Figure 3. Photographs of a forested stream site (Panel A) and an agricultural stream site (Panel B) (photo credit: Jose Shreckinger).

Results

We found very different habitat and physicochemical characteristics along the altitudinal gradient in Napo basin (Table 1). QBR scores varied from 0 in the most disturbed agricultural site to 100 in the least disturbed site. NH4 concentration varied from $1.0\,\mu g\,L^{-1}$ in a less disturbed site to $25\,\mu g\,L^{-1}$ in two agricultural sites. Overall, these sites exhibited considerable variation both physically and chemically.

We did not find *A. vaillanti* in sympatry with rainbow trout in any of our sampling sites. The two taxa were segregated along the altitudinal gradient and by land use (Table 2), with *Astroblepus* inhabiting lower elevation and more agriculturally developed streams and rainbow trout were found in higher elevation, less disturbed sites. A multifactor analysis of variance showed a significant interactive effect between altitude and land use on *Astroblepus spp*. abundance ($p = .05$; Table 1). *Astroblepus spp*. were found in significantly higher abundances (mean = 1.85 fish m^{-2}) in agricultural than less disturbed sites (mean = 0.26 fish m^{-2}; $p = .03$; Figure 4). *A. vaillanti* were also found in significantly higher abundances in sites with poorer riparian vegetation quality QBR ($p = .04$). Finally, presence of rainbow trout was by itself an important variable in the presence or absence of *A. vaillanti*, as the two species were never found in sympatry, irrespective of habitat type.

Our GAMs analysis revealed a strong negative association between abundance and altitude, QBR and IHF (Figure 5). Conversely, *A. vaillanti* abundance increased with temperature, pH, and dissolved oxygen (Figure 5).

Table 2. Summary of Multifactor Analysis of Variance of Effects of Rainbow Trout Presence, Elevation, Habitat, and Physicochemical Parameters on *Astroblepus vaillanti* Abundance.

Variable	Sums of squares	*df*	*F*	*p*
Land use	9.38	1	614.92	.03*
Rainbow trout	0.09	1	0.39	.58
Altitude	0.22	1	14.42	.07
QBR	3.09	1	202.41	.05*
IHF	0.00	1	0.29	.51
Temperature	0.06	1	4.02	.29
Dissolved oxygen	1.48	1	97.10	.66
pH	0.02	1	1.31	.46
Conductivity	0.00	1	0.04	.88
Land use × Altitude	2.76	1	181.22	.05*

Note: Sums of squares, df, F-values, and p-values are provided. QBR = riparian habitat quality; IHF = Index of Fluvial Habitat.
*Significance (assessed at $\alpha = .05$).

These habitat factors are thus the most likely among the study parameters to limit *A. vaillanti* abundance. The relationship between abundance and conductivity, NH_4 concentration, and SRP concentration was highly variable (Figure 5), indicating that these parameters are potentially not limiting factors for abundance, and thus might not be good predictors of habitat suitability for *Astroblepus spp*.

Discussion

To our knowledge, prior to this study, there was little or no published information on the conservation status of

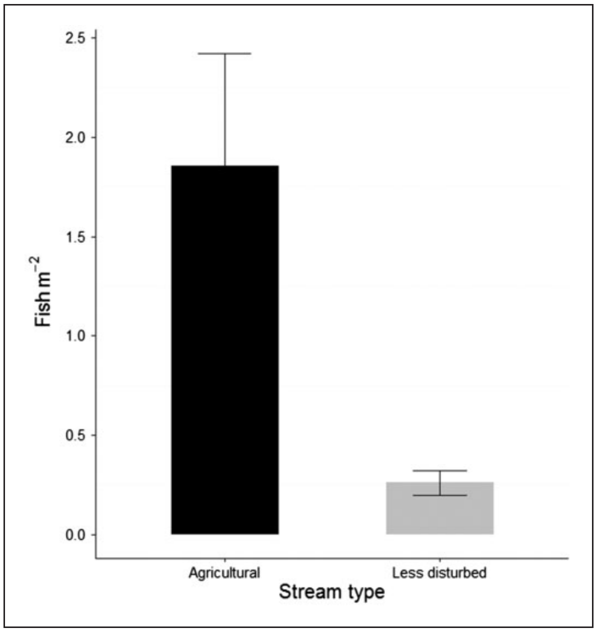

Figure 4. Bar chart representing *Astroblepus vaillanti* abundance in agricultural sites ($n = 6$) and less disturbed sites ($n = 6$).

A. vaillanti or the potential threat to the species stemming from the introduction of rainbow trout. Furthermore, this study was the first to provide species–habitat relationships for *A. vaillanti*, yielding some interesting distinctions in habitat suitability for the species when compared with *A. ubidai*, the only other species of the *Astroblepus* genus for which habitat suitability information exists (Vélez-Espino, 2003, 2006).

For example, removal of riparian vegetation which exposes stream reaches to increased solar radiation, reducing shading and thus increasing temperatures (Jones et al., 1996), is considered a primary threat to *A. ubidiai*. Yet, we found significantly higher abundances of *A. vaillanti* in streams with reduced or absent riparian vegetation (i.e., low QBR scores) due to agriculture than streams with intact riparian zones. Furthermore, abundance of *A. vaillanti* increased with increasing stream temperature, at least within our sampled range, which is largely at the upper extent of expected elevational suitability for the genus, thus temperatures in the study area are cooler than in the habitat of other Astroblepus spp. These findings indicate that habitat suitability indices for

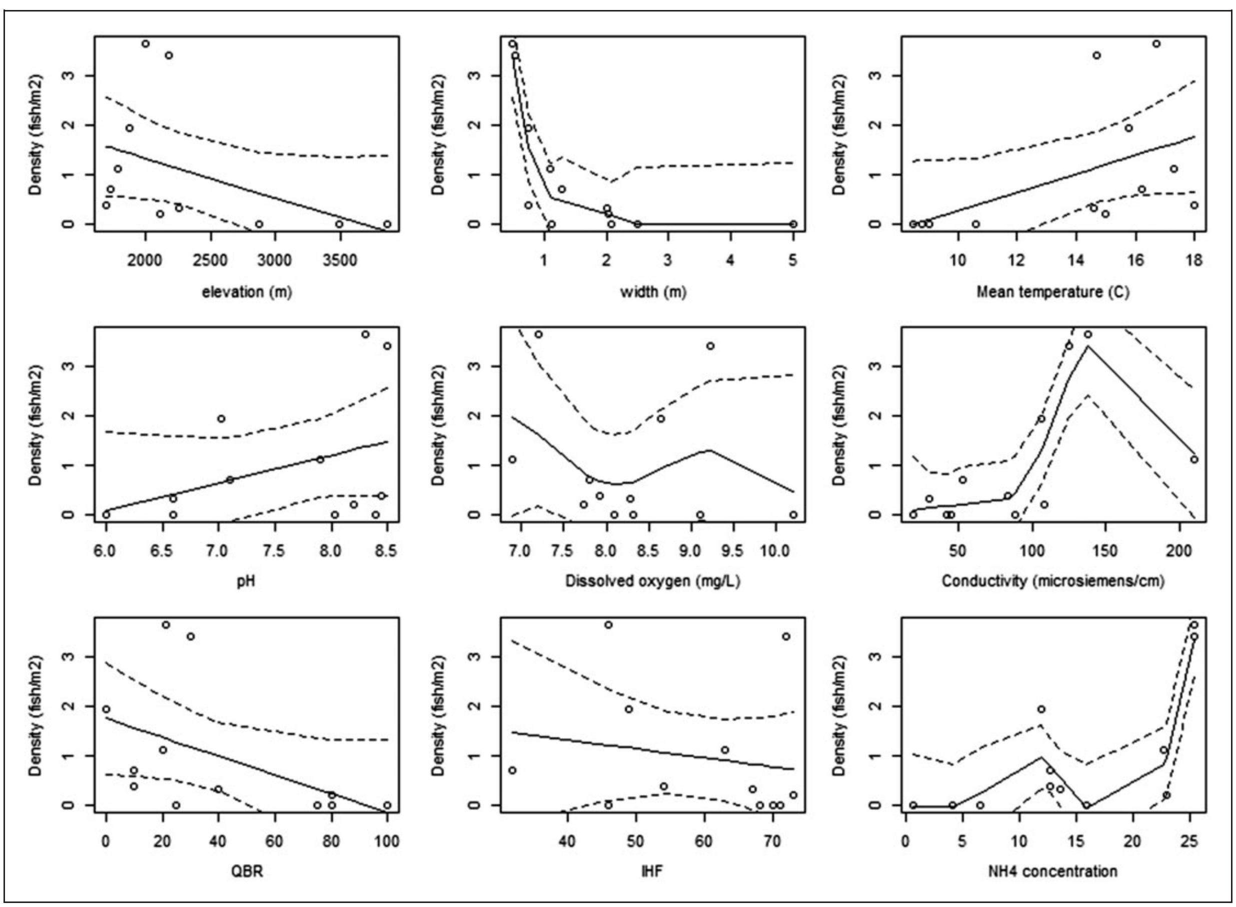

Figure 5. Smoothed curve of the additive effect of individual environmental parameters on estimated *Astroblepus* vaillanti abundance (fish m^{-2}) using Generalized Additive Models (GAMs). Dotted lines represent 95% confidence intervals.

one species of *Astroblepus* may not apply for other species within the genus. Perhaps most interesting was the absence of *A. vaillanti* in the presence of rainbow trout, irrespective of habitat quality. This could indicate that rainbow trout are either eliminating or displacing *A. vaillanti* populations, and could explain the negative relationship between A. vaillanti abundance and habitat quality.

The negative association of *A. vaillanti* abundance with quality riparian habitat and the significantly higher densities found in agricultural streams was a somewhat surprising finding, based on the limited habitat suitability information available for other species of *Astroblepus* (i.e., *A. ubidiai*: Tobes, Gaspar, Peláez-Rodríguez, & Miranda, 2016; Vélez-Espino, 2003, 2006). *A. vaillanti* appears to have distinct habitat requirements from *A. ubidiai*, thus successful management and conservation actions for the two species might look very different. These variable habitat requirements between the two *Astroblepus* species for which habitat suitability are now available highlight the need for similar and more extensive studies of other species within the genus. Moreover, the current *A. vaillanti* distribution might be driven by rainbow trout displacement, rather than habitat suitability, possibly confounding the true habitat requirements of the species.

The other important and somewhat surprising finding of this study was that *A. vaillanti* appeared to occupy a very different niche than rainbow trout, thus the two species might either be naturally segregated or rainbow trout are displacing *A. vaillanti* through competition or predation as *A. vaillanti* appeared to exploit highly disturbed habitats while rainbow trout did not. The highly disturbed stream sites had visibly higher algal production, which could potentially explain the higher abundances of *A. vaillanti*. However, we have not yet conducted algal assessments or diet analysis to evaluate this hypothesis.

In our study, rainbow trout were highly associated with colder stream temperatures, intact riparian vegetation, and less agricultural development whereas *A. vaillanti* abundances were significantly higher in warmer streams with more agricultural development. While this study does not rule out displacement by rainbow trout, our study indicates that *A. vaillanti* may find refugia in highly disturbed streams that would be unsuitable to nonnative trout. These findings highlight the need for further studies, particularly experimental releases of *A. vaillanti* into streams containing rainbow trout to more conclusively confirm or refute the displacement hypothesis.

Implications for Conservation

Habitat quality and abundance are both strongly considered in the criteria for the listing of species endangerment developed by the World Conservation Union (International Union for the Conservation of Nature and Natural Resources, 2001). Yet, most of the information available on the genus *Astroblepus* is for a single species *A. ubidiai* due to "critically endangered" IUCN status. Available data are very limited for other species of *Astroblepus*, though many species of the genus face the same or additional threats. This study provides the first quantitative estimates of abundance and habitat suitability relationships for *A. vaillanti*, which could be useful for conservation, management, and future research on the genus in the Napo River Basin of Ecuador. For poorly studied species, the IUCN will assign a threat category based on habitat deterioration, therefore understanding habitat suitability for a species important in these decisions. It is our hope that the findings of this study will assist in local conservation and management of *A. vaillanti* and could be useful in an IUCN Redlist Assessment for the species.

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Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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