

# Do protected areas conserve neotropical freshwater fishes? A case study of a biogeographic province in Venezuela

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## Abstract

*Do protected areas conserve neotropical freshwater fishes? A case study of a biogeographic province in Venezuela.*— The effectiveness of protected areas to conserve freshwater fishes is limited because these areas are not usually congruent with regional patterns of fish species richness and distribution. We compared the richness, distribution and abundance of coastal freshwater fishes in a biogeographic province of Venezuela to determine their conservation status. We also estimated the relevance of existing protected areas in conserving fishes in different physiographic units and tributaries by evaluating species richness and distribution. The ichthyofauna (72 spp., ~30% endemic, ~10% threatened) was distributed according to orography, drainage and physiographic units. Most protected areas had limited effectiveness for fish conservation, mainly because they were too small or included only fragments of tributaries or drainages, or because they were located only in highland drainages where species diversity was minimal. To adequately protect freshwater fishes in this province the existing protected areas should be modified and expanded.

Key words: Aquatic biodiversity, Biogeographic province, National parks, Coastal rivers.

## Resumen

*¿Las áreas protegidas conservan los peces continentales neotropicales? un caso de estudio para una provincia biogeográfica en Venezuela.*— La efectividad de las áreas protegidas para la conservación de peces continentales es limitada ya que generalmente estas no son congruentes con los patrones regionales de la riqueza y distribución de las especies de peces. Como caso de estudio comparamos la riqueza, distribución y abundancia de la ictiofauna en ríos costeros de una provincia biogeográfica de Venezuela para determinar su estatus de conservación. Además, también estimamos la efectividad de las áreas protegidas para la conservación de la ictiofauna según la riqueza y distribución de especies en diferentes unidades fisiográficas y afluentes. La ictiofauna (72 spp., ~30% endémicas; ~10% amenazadas) se distribuyó acorde con la orografía, cuencas y unidades fisiográficas. La mayoría de áreas protegidas evidenciaron una efectividad baja para la conservación de peces, principalmente porque eran muy pequeñas o incluían sólo fragmentos de afluentes o cuencas, o porque estaban localizadas en zonas de montaña, donde la diversidad de especies era mínima. Para proteger con eficacia adecuada a los peces continentales de la provincia, las áreas protegidas existentes deberían ser modificadas y expandidas.

Palabras clave: Biodiversidad acuática, Provincia biogeográfica, Parques nacionales, Ríos costeros.

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## Introduction

Areas protected for conservation are often set up on the basis of available regional inventories of landscapes, biogeographic patterns of terrestrial biota, or the need to protect populations of specific, usually terrestrial, species. A lack of complete biogeographic records often leads to the creation of protected areas that are later found to exclude important habitats and species, and thus limit their relevance for conservation. This lack of foresight is most evident and worrisome when considering freshwater ecosystems and their fish fauna. Information about fishes is not usually taken into consideration when designing park and refuge systems. This is paradoxical since today we know that freshwater fishes are among the most endangered species on the planet as a result of habitat loss and degradation, water pollution, species invasion and climate change (Abell et al., 2009).

Terrestrial protected areas have been shown to have inadequate design and coverage to sufficiently conserve aquatic ecosystems (Herbert et al., 2010; Barletta et al., 2010). The situation is dire in the Neotropics where the largest diversity of freshwater fishes occurs, but our scant knowledge of fish taxonomy, biology and ecology hinders the design of effective strategies for their conservation. Thus, many protected areas in South America include only fragments of watersheds or streams and so fail to include essential regions necessary to guarantee the continuity of hydrosystem function and maintenance of freshwater biodiversity.

Conservation biologists have a serious interest in determining how to best evaluate the effectiveness of protected areas, but freshwater hydrosystems and fishes have only recently been taken seriously into account. Newer methods now include a simple quantification of fish distribution coverage, freshwater habitat features and their relationships with attributes of protected areas or drainages (Herbert et al., 2010; Nogueira et al., 2010) and the use of rarity, vulnerability or conservation indices for fishes (Abellán et al., 2005; Bergerot et al., 2008). Most evaluations are applied to a specific tributary or drainage, and few take the regional biogeographic context into account. In biogeographic provinces, biotas have evolved together, and they show patterns and gradients of species richness and distribution that differ at different scales (Whittaker & Fernández-Palacios, 2007). Evaluations of protected area systems that take biogeographic context into consideration will provide more useful information for effective conservation.

The Western Caribbean province (WCP) –a zoogeographic unit proposed to delimit the freshwater fishes of coastal Caribbean drainages in Venezuela–includes streams that originate in the high Andes Mountains, the arid hills of the Coriano range and humid valleys in the limits of the Coastal range (Rodríguez-Olarte et al., 2009). This set of drainages comprises only around 30,000 km<sup>2</sup> but it includes a remarkable variety of landscapes and biotas, reflected in its species-rich freshwater fish fauna and its many

endemics. Several protected areas have been created in the WCP (ABRAE, or areas under special administration regime). These include national parks and natural monuments. In our study area these comprise mainly mountain regions, a few wildlife refuges in lowland areas near river deltas, and areas adjacent to marine parks. Also, in the WCP, two areas of special interest for the conservation of biodiversity come together: the Tropical Andes Hotspot (Myers et al., 2000), which includes several terrestrial ecoregions (Olson & Dinerstein, 2002) and the Caribbean Freshwater Ecoregion of South America and Trinidad (Abell et al., 2008).

Recent work in the WCP shows that most aquatic ecosystems and their fishes are at risk and several species have been listed as threatened (Rodríguez & Rojas-Suárez, 2008; Rodríguez-Olarte et al., 2007; 2009). Since the distribution patterns of fish species vary within drainage and even more so within a biogeographic province, we hypothesised that the current protected area network of this biogeographic province did not adequately protect the variety of aquatic ecosystems and the fishes found there. To design a project that would systematically document this, we evaluated the protected areas of the WCP as a case study, with respect to the freshwater fishes, incorporating both historical and recent records for fish species distribution.

## Methods

### Historical records, fish sampling and geographical data

We used museum collections (CPUCLA, MBUCV, MCNG and MHNLS) and published accounts to obtain historical records of fish distribution in the province (Reis et al., 2003; Rodríguez-Olarte et al., 2009). We also consulted records from databases (Froese & Pauly, 2010). We estimate that the historical records thus obtained would be sufficient in the WCP to delimit species distributions. We also considered that data on fish abundance of historical records are from sufficiently long-term observations to infer tendencies in variation for most species and most drainages.

We collected standardized samples from 32 different sites (fig. 1) among drainages of the Andes (Tocuyo), Coastal (Aroa, Yaracuy, Urama) and Coriano mountain ranges (Ricoa, Hueque, Coro, Mitare and Tucurere). At each locality, the sampling transect was about 50 m long and less than 1.5 m deep. We used electroshocking gear with hand nets and seines to capture fishes in three successive passes (Lobón-Cerviá, 1991). We collected samples ( $n = 120$ ) from foothills and mountain streams, concentrating efforts towards the end of the wet and dry seasons (September–October and February–March) from 2005 to 2007.

We also collected fish samples at other sites (207 localities, fig. 1), most frequently from the foothill floodplains and river mouths, using non-standardized methods, electroshockers, seines (5 x 2 m, 0.5 mm mesh),

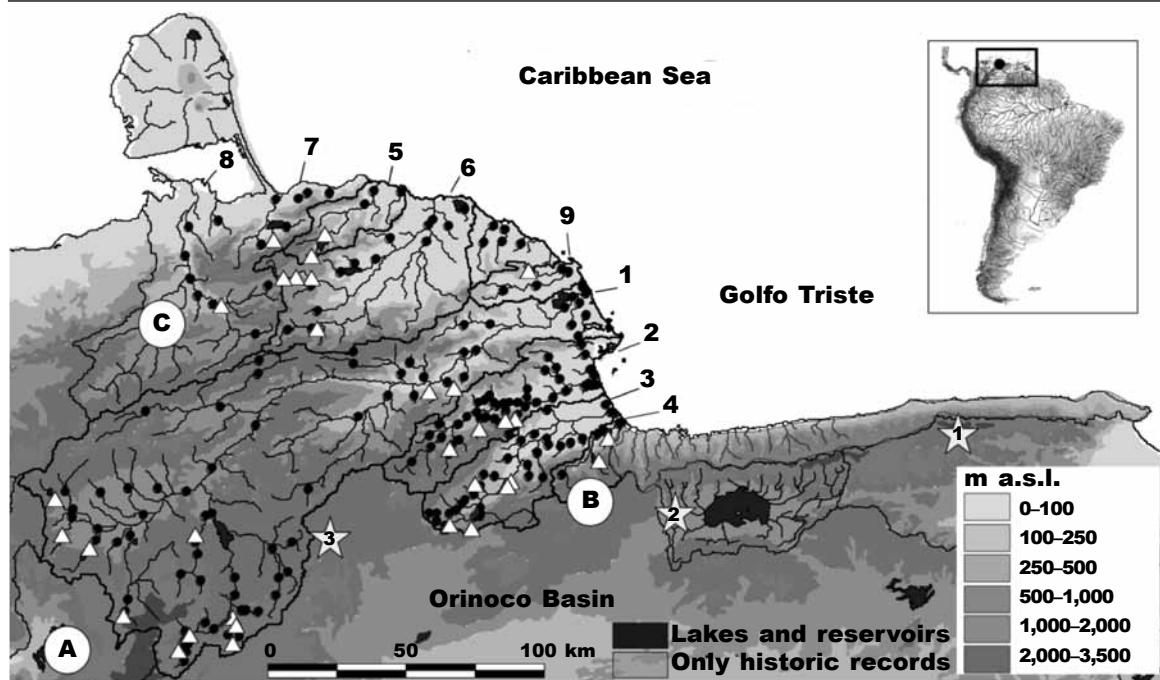


Fig. 1. Western Caribbean province of Venezuela (WCP): ● Historical records sites; △ Localities where standardized sampling was applied from 2005 to 2007; ☆ Main cities (1. Caracas; 2. Valencia; and 3. Barquisimeto). The drainages are: 1. Tocuyo; 2. Aroa; 3. Yaracuy; 4. Urama; 5. Ricoa; 6. Hueque; 7. Coro; 8. Mitare; and 9. Tucurere. Mountains shown are: A. Andes; B. Coastal range; C. Coriano range.

Fig. 1. Provincia Caribe Occidental de Venezuela (WCP): ● Registros históricos; △ Localidades donde se aplicaron muestreos estandarizados del 2005 al 2007; ☆ Principales ciudades (1. Caracas; 2. Valencia y 3. Barquisimeto). Las cuencas son: 1. Tocuyo; 2. Aroa; 3. Yaracuy; 4. Urama; 5. Ricoa; 6. Hueque; 7. Coro; 8. Mitare y 9. Tucurere. La orografía regional está representada por: A. Los Andes; B. Cordillera de la Costa y C. Sistema Coriano.

hand nets, pneumatic harpoons, traps, and hook and line. These samples were also considered as historical records. In a few of the smallest drainages, especially those of the Coastal range (fig. 1), standard fishing methods could not be applied, so we used only historical records. Fishes were usually identified and counted in the field and returned live, but in some cases representative samples were preserved in 10% formalin, later transferred to 70% ethanol, and deposited in the Colección Regional de Peces (CPUCLA–UCLA) and the Museo de Ciencias Naturales Guanare (MCNG–UNELLEZ) following identification.

The ABRAE that we evaluated here are those designated principally for conservation: national parks, natural monuments, wildlife refuges and fauna reserves. We classified and quantified the ABRAE in the province according to type, location, surface area, coverage of physiographic units (lowland floodplains, foothills or mountains), tributaries and drainages. Geographic data were taken from Rodríguez et al. (2004), Lehner et al. (2006) and <http://www.feow.org>.

#### Data analysis

##### Conservation status of the fish fauna

Species were classified by distribution type: endemic to the province, or occurring in other Caribbean and/or the Orinoco drainages. We used relative abundance from all samples standardized from 2005 to 2007, but for other samples we used five categories of abundance: abundant, common, scarce, rare and very rare. Conservation status follows IUCN criteria (IUCN, 2001, 2003, 2006), but because information needed to accurately classify many species of fish from the WCP is still lacking, non-subjective assignment to a threat category was often difficult. To assign a species to a category ('critically endangered', 'endangered', 'vulnerable', 'near threatened', 'of least concern' and 'data deficient') we used the following criteria: (a) decreasing populations, (b) size of the geographic area of distribution, (c) small population size, (d) very small populations or distribution area

Table 1. Conservation status of freshwater fishes in WCP: EN. Endemic species to the province (E) and/ or that occur in Caribbean (C) or Orinoco (O) drainages; DI. Endemic species classified as occurring in Andean (●), Coriano (▲) or Coastal mountain ranges (■); AB. Abundance (expressed as a relative proportion for standardized samples; in non-standardized samples, abundance classes were assigned as abundant [a], common [c], scarce [e], rare [r] and very rare [vr]); TC: threat categories: critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), of least concern (LC) and data deficient (DD). Non-native species (nn) were not included in the categories.

Tabla 1. El estatus de conservación de los peces continentales en WCP: EN. Especies endémicas a la provincia (E) y/o que habitan en cuencas del Caribe (C) u Orinoco (O); DI. Especies endémicas según su presencia en los sistemas orográficos (Andes (●), sistema Coriano (▲) y cordillera de la Costa (■); AB. Abundancia (proporción relativa en muestras estandarizadas; en muestras no estandarizadas, las tipologías de abundancia son: abundantes [a], comunes [b], escasas [e], raras [r] y muy raras [vr]); TC. Se asignan los tipos de amenaza: en peligro crítico (CR), en peligro (EN), vulnerable (VU), casi amenazado (NT), preocupación menor (LC) y datos insuficientes (DD). Las especies no nativas (nn) no fueron incluidas dentro de las categorías.

Species	EN	DI	AB	TC	Species	EN	DI	AB	TC
<i>Astyanax viejita</i>	C		9.8	LC	<i>Chaetostoma milesi</i>	CO		0.1	DD
<i>Astyanax magdalenae</i>	C		0.8	LC	<i>Chaetostoma</i> sp. Alto Tocuyo	E	●	8.4	LC
<i>Astyanax metae</i>	O		4.2	LC	<i>Chaetostoma stanni</i>	E	●■	4.6	LC
<i>Astyanax venezuelae</i>	O		0.2	LC	<i>Chaetostoma yurubiense</i>	E	■	0.3	LC
<i>Bryconamericus alpha</i>	O		1.3	LC	<i>Chaetostoma</i> sp. Tocuyo N	E	●	1.0	LC
<i>Bryconamericus charalae</i>	E	■	e	DD	<i>Farlowella mariaelenae</i>	CO		< 0.1	DD
<i>Bryconamericus cismontanus</i>	O		12	LC	<i>Farlowella martini</i>	E	■	0.2	NT
<i>Bryconamericus loisae</i>	C		c	DD	<i>Farlowella vittata</i>	CO		r	DD
<i>Creagrutus crenatus</i>	E	●	0.9	LC	<i>Hypostomus pagei</i>	E	●■	1.7	LC
<i>Creagrutus hildebrandi</i>	C		0.8	LC	<i>Rineloricaria rupestris</i>	C		0.9	LC
<i>Creagrutus lassoi</i>	E	●■	6.6	LC	<i>Pimelodus blochii</i>	O		< 0.1	nn
<i>Creagrutus lepidus</i>	E	■	0.2	VU	<i>Batrochoglanis mathisoni</i>	E	●■	< 0.1	EN
<i>Creagrutus melasma</i>	CO		1.1	LC	<i>Trichomycterus arleoi</i>	E	■	0.9	LC
<i>Colossoma macropomum</i>	O		–	nn	<i>Trichomycterus kneri</i>	C		0.6	LC
<i>Gephyrocharax melanocheir</i>	C		3.4	LC	<i>Trichomycterus</i> sp. Tocuyo	E	●	0.8	LC
<i>Gephyrocharax valencia</i>	O		< 0.1	LC	<i>Apteronotus</i> sp. Yaracuy	E	■	0.1	NT
<i>Gephyrocharax venezuelae</i>	C		2.0	LC	<i>Gymnotus carapo</i>	CO		< 0.1	DD
<i>Hemibrycon jabonero</i>	C		8.6	LC	<i>Brachyhypopomus diazi</i>	CO		< 0.1	NT
<i>Hyphessobrycon fernandezi</i>	E	●■	< 0.1	NT	<i>Oncorhynchus mykiss</i>			c	nn
<i>Hyphessobrycon sovichthys</i>	C		e	DD	<i>Poecilia caucana</i>	C		0.4	LC
<i>Hyphessobrycon paucilepis</i>	E	●	< 0.1	DD	<i>Poecilia dauli</i>	C		d	DD
<i>Nanocheiroidon insignis</i>	C		e	DD	<i>Poecilia koperi</i>	C		< 0.1	DD
<i>Roebooides dientonito</i>	CO		0.6	LC	<i>Poecilia reticulata</i>	O		2.0	LC
<i>Characidium chupa</i>	CO		1.2	LC	<i>Poecilia sphenops</i>	C		r	DD
<i>Steindachnerina argentea</i>	CO		< 0.1	LC	<i>Pseudolimia heterandria</i>	C		c	DD
<i>Hoplias malabaricus</i>	CO		0.2	LC	<i>Cyprinodon dearborni</i>	C		c	LC
<i>Lebiasina erythrinoides</i>	CO		3.0	LC	<i>Austrofundulus lehoignei</i>	E	●■	vr	CR
<i>Parodon apolinari</i>	CO		1.3	LC	<i>Rivulus hartii</i>	C		< 0.1	LC
<i>Prochilodus mariae</i>	O		–	nn	<i>Synbranchus marmoratus</i>	CO		< 0.1	LC
<i>Corydoras venezuelanus</i>	CO		< 0.1	LC	<i>Andinoacara pulcher</i>	C		5.5	LC
<i>Hoplosternum littorale</i>	O		e	DD	<i>Caquetaia kraussii</i>	C		< 0.1	nn
<i>Cetopsis orinoco</i>	O		< 0.1	DD	<i>Cichla</i> sp.	O		–	nn

Table 1. (Cont.)

Species	EN	DI	AB	TC	Species	EN	DI	AB	TC
<i>Cetopsorhamdia</i> sp. Aroa	E	■	< 0.1	DD	<i>Crenicichla geayi</i>	O		2.3	LC
<i>Cetopsorhamdia</i> sp. Tocuyo	E	●	0.2	DD	<i>Geophagus</i> sp.	O		–	nn
<i>Pimelodella odynea</i>	C		3.2	LC	<i>Oreochromis</i> sp.			–	nn
<i>Rhamdia quelen</i>	CO		2.2	LC	<i>Eleotris pisonis</i>	C		c	DD
<i>Rhamdia guatemalensis</i>	C		c	LC	<i>Awaous banana</i>	C		< 0.1	LC
<i>Ancistrus gymnorhynchus</i>	CO		2.8	LC	<i>Sicydium plumieri</i>	C		r	LC
<i>Ancistrus falconensis</i>	E	▲	2.6	LC	<i>Agonostomus monticola</i>	C		< 0.1	DD
<i>Ancistrus triradiatus</i>	CO		< 0.1	LC					

and (e) analysis of threat of extinction. Because biological and ecological data (growth, reproduction, diet, etc.) were not available for most species we used information for similar species, field observations and historical records instead. Demographic data on fish populations are not available to assess the imminence of extinction from natural habitat (*criterion e*). However, we consider that the viability of populations of fishes can be inferred from information about their very restricted distribution, and/or by evaluating the threat of habitat destruction.

#### Biogeographical patterns

For the biogeographical analyses we used only the standardized samples from rivers considered to be in pristine condition, according to our experience (17 localities; 64 collections). To compare the association of species with orography, drainages and physiographic units across the WPC we used a non-metric multidimensional scaling analysis (NMS) based on the Bray–Curtis distance measure and applied to  $\ln(x + 1)$  transformed data. This analytical method represents relationships between samples in a similarity matrix (Clarke & Warwick, 1994). The graphic was rotated for easier comparison. The robustness of the NMS ordination was indicated by the average stress values based on a two-dimensional solution, and a Monte Carlo stress test of randomized data was done with 999 permutations. Since the conservation status of each species is linked to its distribution and associated with certain habitats or drainages, we classified distributions as occurring in physiographic units, and determined the association of these with respect to drainages with Indicator Species Analysis (ISA, Dufrêne & Legendre, 1997). Here, this analysis provides an indicator value, associated with a probability, for each species with respect to a physiographic unit or drainage. Significance was evaluated using a Monte Carlo test (10,000 permutations). The NMS and ISA were evaluated using the program PC-ORD 4.41 (McCune & Mefford, 1999).

#### Effectiveness of protected areas

To evaluate the significance of species richness in protected areas network we used species–area relationships. We related the accumulated area of the ABRAE in chronological order according to the date of its creation and the number of species accumulated therein (recorded or estimated). We also evaluated the coverage and borders of hotspots and terrestrial and aquatic ecoregions with respect to the distribution of freshwater fishes.

We classified the effectiveness of ABRAE by creating relative coverage indices for (a) physiographic units, (b) tributaries and (c) species richness. In the first case we estimated that ABRAE that included a wider variety of physiographic units would have a higher relevance for conservation. We assigned the following indices for these: lowland floodplains (60%); foothills (30%) and mountains (10%). An index value of maximum coverage, for example, suggests that an ABRAE includes all three physiographic units. In the same way we estimated that an ABRAE that included an entire tributary from its origin to its confluence with a major river or the sea would have greater impact for conservation of freshwater fishes than an ABRAE that only included fragments of tributaries, independent of physiographic units. Therefore, we rated ABRAEs by comparing the total length of the major tributary associated with an ABRAE with the length of the tributary included within the boundaries of that ABRAE. In this index of tributary coverage, a maximum value indicated that the entire length of the major river associated with an ABRAE occurred within its boundaries.

To estimate the ABRAE coverage of species richness we compared total species richness of the principal tributary associated with an ABRAE to the number of species found within its boundaries. Here, maximum values indicated that all species present in a river could be found within the ABRAE. The sum of these three components –physiographic units, tributaries and species richness– was the value assigned to each ABRAE to rate its effectiveness for the conservation of freshwater fishes. These values

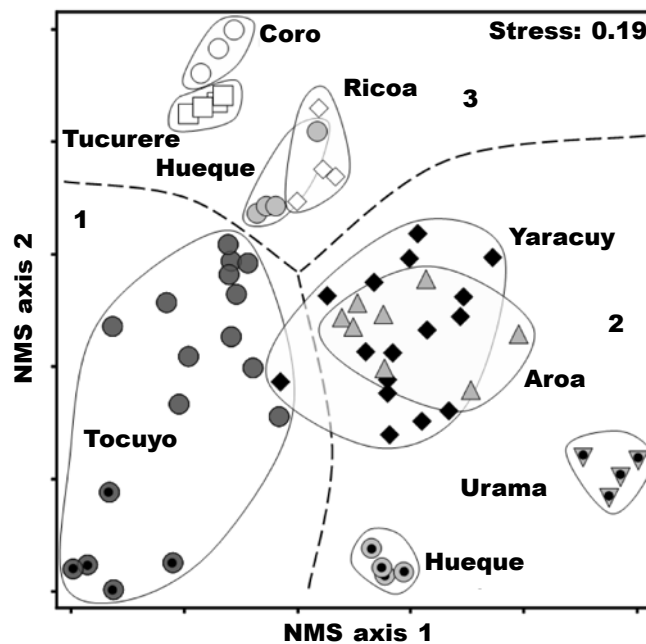


Fig. 2. A non-metric multidimensional scaling (NMS) applied on samples from rivers considered to have pristine conditions performed in the WPC from 2005 to 2007. The results suggest that the ichthyofauna is associated with the orography, drainages and altitude. The broken lines separate the drainages according to orography (1. Andes; 2. Coastal range; 3. Coriano range), except in the Hueque drainage. Symbols containing a black dot are localities in mountains; the rest are mostly situated in the foothills.

Fig. 2. Escalado multidimensional no métrico (NMS) para las muestras en ríos de condiciones originales en la WPC desde 2005 hasta 2007. Los resultados sugieren que la ictiofauna está asociada a la orografía, las cuencas y la altitud. Las líneas punteadas separan las cuencas según la orografía (1. Andes; 2. Cordillera de la Costa; 3. Sistema Coriano), excepto en la cuenca Hueque. Los símbolos que contienen un punto negro son localidades en montañas y el resto se sitúan generalmente en piedemontes.

were rated into four categories: very low (< 75%), low (75–150%), medium (151–225%) and high effectiveness (> 225%).

## Results

About 30% of the 72 species recorded are endemic, and most of them are from Andean or Coastal ranges. The families with the most species are Characidae (24 spp.) and Loricariidae (13 spp.). About half of the loricariids are endemic (table 1). Locality records showed that several endemic species were restricted to very small drainages (< 5,000 km<sup>2</sup>) or physiographic units, usually small mountain watersheds, and others were found only in temporary rain pools in the lowlands. The drainages of the Tocuyo, Aroa and Yaracuy Rivers were recognized as having the highest species richness and endemism in the province, and as such are of highest priority for conservation.

Most of the more abundant species (*Bryconamericus cismontanus*, *Astyanax viejita*, *Hemibrycon jabonero*) maintained high abundances and many occurred

throughout the WCP. However, some endemic species with restricted distribution had high local abundance (*Chaetostoma* sp. Alto Tocuyo, *Creagrutus lassoi*). The annual killifish *Austrofundulus leohoignei*, which lives in temporary rain pools in the lowlands, had the smallest known distribution of all the species studied. The pseudopimelodid catfish, *Batrochoglanis mathisoni* which lives among rocks in clear foothills and floodplain streams was very rarely collected (table 1).

Most species fell into the conservation category 'of least concern' (63%); they had widespread distribution in one or more drainages, and they also occurred outside the province in some cases. The frequency of appearance of these species in the samples and their abundance did not show notable variation. In the category of 'near threatened' we included *Brachyhypopomus diazi* (table 1), which is found in the Aroa and Yaracuy drainages. *A. leohoignei*, known from only a few temporary rain pools in the lowlands of the Aroa and Tocuyo drainages was classified as 'critically endangered', and *B. mathisoni* was classified as 'endangered'. We classified about 28% of the species encountered as 'data deficient', but several



Table 2. The associations of species with particular drainages were statistically significant ( $P$ ) according to indicator values (IV) of the indicator species analysis. The distributions were also related to orography: MR. Mountain ranges; E. Endemic species; M. Species that occur in the mountains.

Tabla 2. La asociación de especies respecto a las cuencas, según los indicadores (IV) en el análisis de especies indicadoras, tuvo significancia estadística ( $P$ ). Las distribuciones también estuvieron relacionadas con la orografía: MR. Cadenas montañosas; E. Especies endémicas; M. Especies que habitan en las montañas.

MR	Drainages	Species	IV	$P$	
Coriano	Tucurere	<i>Astyanax magdalenae</i>	62	0.004	
		<i>Gephyrocharax venezuelae</i>	62	0.002	
		<i>Synbranchus marmoratus</i>	48	0.007	
	Coro	<i>Creagrutus hildebrandi</i>	70	0.001	
	Mitare	<i>Agonostomus monticola</i>	50	0.020	
		<i>Bryconamericus cismontanus</i> M	34	0.001	
		<i>Hypostomus pagei</i> E	47	0.007	
			<i>Rineloricaria rupestre</i>	45	0.019
	Hueque	<i>Ancistrus falconensis</i> E, M	41	0.023	
	Ricoa	–	–	–	
Coastal	Urama	<i>Characidium chupa</i> M	53	0.002	
		<i>Chaetostoma stanni</i> E	31	0.046	
		<i>Trichomycterus arleoi</i> E, M	35	0.020	
	Yaracuy	<i>Apteronotus</i> sp. Yaracuy E	35	0.027	
		<i>Creagrutus lassoi</i> E, M	35	0.031	
	Aroa	<i>Chaetostoma yurubiense</i> E, M	32	0.033	
Andean	Tocuyo	<i>Chaetostoma</i> sp. Alto Tocuyo E, M	40	0.025	

of these are widespread throughout the province. We found eight introduced species; these were usually found in reservoirs and artificial ponds, but *P. mariae* (Prochilodontidae) and *P. blochii* (Pimelodidae) also occurred in the main channels of some rivers.

Species association with orography, drainages and physiographic units was evident. The NMS ordination accounted for 74.8% of the variance (axis 1: 44.8%; axis 2: 30%; fig. 2). The final mean stress of 0.19% indicated a potentially useful two-dimensional solution. The ordination evaluation recognized patterns of the ichthyofauna in orographic scale, and also for species restricted to mountains. About 20% of the fishes in the WCP –including about half of the endemics– showed significant indication values for almost all drainages (table 2). Of these species, about half occurred in mountains.

Although our analysis showed that a little more than 17% of the entire surface area of the WCP was included in some sort of ABRAE, nearly 90% of these protected areas were small (less than 500 km<sup>2</sup>) and mainly included mountain regions (table 3). The drain-

ages of the Coastal range had nearly one third of their area included in protected areas, but this coverage was only about 10% of the Coriano range, and even less, about 6%, of the Andean drainages. Thus, in our study area most ABRAE protect highlands.

Species richness did not necessarily increase with increased surface area of the ABRAE. The relationship between the accumulated total number of species and the accumulated area of the ABRAE was expressed as a curve that tended to become saturated as we neared 83% of the total species richness recorded in the WCP (fig. 3A). Excluding the ABRAE located in mountain regions and/or of small size, we found a direct relationship between the number of species recorded for each drainage and the number of species found in the river stretch or affluent under protection. This relationship was expressed as a linear function with high significance ( $R^2 = 0.88$ ;  $P = 0.0006$ , fig. 3B).

Including different physiographic units revealed the effectiveness of the ABRAE. Lowlands were the physiographic unit with least protection and highest species diversity. Tributaries entirely included within

Table 3. Protected areas in the Western Caribbean Province (WCP) and their effectiveness for the conservation of fishes. The coverage for drainages refers to the percentage of a local drainage covered by each ABRAE. The coverage for physiographic units (column I) are plains (A), foothills (B) and mountains (C). Coverage for tributaries is given in column II. The coverage for richness (column III) is expressed in St (total number of species) and Se (total number of endemic species) recorded throughout the course of the main tributary associated with each ABRAE. Sp is the number of species estimated to occur within the protected area. The coverage values in parentheses are percentages and the effectiveness of each ABRAE for the conservation of fishes is the sum of the coverages ( $\Sigma = I + II + III$ ).

ABRAE	Area (km <sup>2</sup> )	Altitude (m a.s.l.)	Coverages
			Drainages (%)
<b>Parks</b>			
Henri Pittier 1937	1,078	0–2,436	Coastal range (95)
Ávila 1958	819	120–2,765	Coastal range (90)
Yurubí 1960	237	150–1,950	Aroa (7), Yaracuy (6)
Yacambú 1962	269	500–2,280	Tocuyo (< 5)
Quebrada del Toro 1969	49	400–1,120	Tocuyo (< 1), Hueque (< 1)
Morrocoy 1974	321	0–285	Aroa (< 5), Tocuyo (< 1)
Juan Crisóstomo F. 1987	191	200–1,500	Hueque (< 5), Ricoa (17), Coro (15), Mitare (< 1)
San Esteban 1987	431	0–1,830	Coastal range (80)
Dinira 1988	459	1,800–3,585	Tocuyo (< 5)
Saroche 1989	346	500–1,300	Tocuyo (< 5)
<b>Monuments</b>			
María Lionza 1960	158	210–1,205	Yaracuy (< 5)
Pico Codazzi 1991	119	600–2,429	Coastal range (40)
<b>Refuges</b>			
Cuare 1972	118	0–285	Tocuyo (< 1)
<b>Reserve</b>			
Tucurere 2001	178	0–40	Tucurere (43), Tocuyo (< 1)
Hueque–Sauca 2005	372	0–20	Hueque (9)
<b>Total ABRAE</b>	<b>5,145</b>		<b>WPC (17.2)</b>

an ABRAE were quite rare, and those that did exist were usually very small drainages that emptied directly into the sea. The average coverage of total species richness protected by an ABRAE did not exceed 50% (table 3). The ABRAE with the smallest percentage of fish species protected were the smaller ones located in the mountains, but these ABRAE included most of the endemic species known from this physiographic unit. On the other hand, several endemic species that occurred on floodplains or in foothills tributaries had only a very small portion of their known distribution areas protected by existing ABRE.

The only ABRAE with a high score of effectiveness for freshwater fishes was the Henry Pittier National Park (Coastal range) which contained some 30 species in its major river, with most of those restricted to the lower stretch of the river. Several ABRAE in the WCP were classified as having low and very low effectiveness for conservation of freshwater fishes. The ABRAE associated with drainages or tributaries with higher species richness and endemism were found to have medium effectiveness for fish conservation (Aroa and Yaracuy River drainages) and protect about half of the freshwater species found in those drainages. The ABRAE with less restrictive protection rules, such



Tabla 3. Las áreas protegidas en la Provincia Caribe Occidental (WCP) y su efectividad para la conservación de la ictiofauna. La cobertura de las cuencas se refiere al porcentaje de la cuenca local cubierto por cada ABRAE. La cobertura de unidades fisiográficas (columna I) se expresa en planicies (A), estribaciones (B) y montañas (C). La cobertura de afluentes se da en la columna II. La cobertura de la riqueza (columna III) es expresada mediante el número total de especies (St) y el número total de especies endémicas (Se) registradas en todo el curso del principal afluente asociado a cada ABRAE. Sp es el número de especies que ocurren dentro del área protegida. Los valores de cobertura en paréntesis son los porcentajes y la efectividad de cada ABRAE para la conservación de la ictiofauna es la suma de las coberturas ( $\Sigma = I + II + III$ ).

Coverages		III			Effectiveness	
I	II	St	Se	Sp	$\Sigma$	Class
BC(40)	(100)	30	4	30(100)	240	High
BC(40)	(90)	30	2	22(73)	203	Medium
BC(40)	(80)	48	8	35(73)	193	Medium
C(10)	(20)	16	2	4(25)	55	Very low
C(10)	(20)	35	4	8(23)	53	Very low
B(30)	(100)	18	3	8(44)	170	Medium
C(10)	(40)	18	3	6(33)	83	Low
BC(40)	(90)	30	4	28(93)	223	Medium
C(10)	(20)	36	2	2(6)	36	Very low
BC(40)	(3)	8	1	1(13)	56	Very low
BC(40)	(100)	42	6	28(67)	207	Medium
C(10)	(20)	30	1	2(7)	37	Very low
AB(90)	(20)	28	2	12(43)	153	Medium
AB(90)	(60)	25	1	18(72)	222	Medium
AB(90)	(60)	22	1	15(68)	218	Medium

as the wildlife refuges and faunal reserves, covered part of the lowland floodplains but since they offered modest protection, they were classified as being of medium effectiveness.

### Discussion

Of all the species of fishes included in the different threat categories for Venezuela (Rodríguez & Rojas-Suárez, 2008) a little more than 90% occur only in the coastal Caribbean drainages, and nearly 20% of those occur only in the WCP. Although many species

are not currently included in any IUCN category, in the near future, many of them face real threats. For example, several species of variable abundance but endemic to one drainage, physiographic unit or tributary (*Bryconamericus charalae*, *Creagrutus crenatus*, *Hyphessobrycon paucilepis*, *Chaetostoma yurubiense*) were included in the categories of least concern' or 'data deficient'. This situation, a result of our lack of biological and biogeographic information, prohibits a strict application of the protocol for conservation classification. We believe that this is the case for many other compendia of endangered species for South American countries, such as Colombia (Mojica

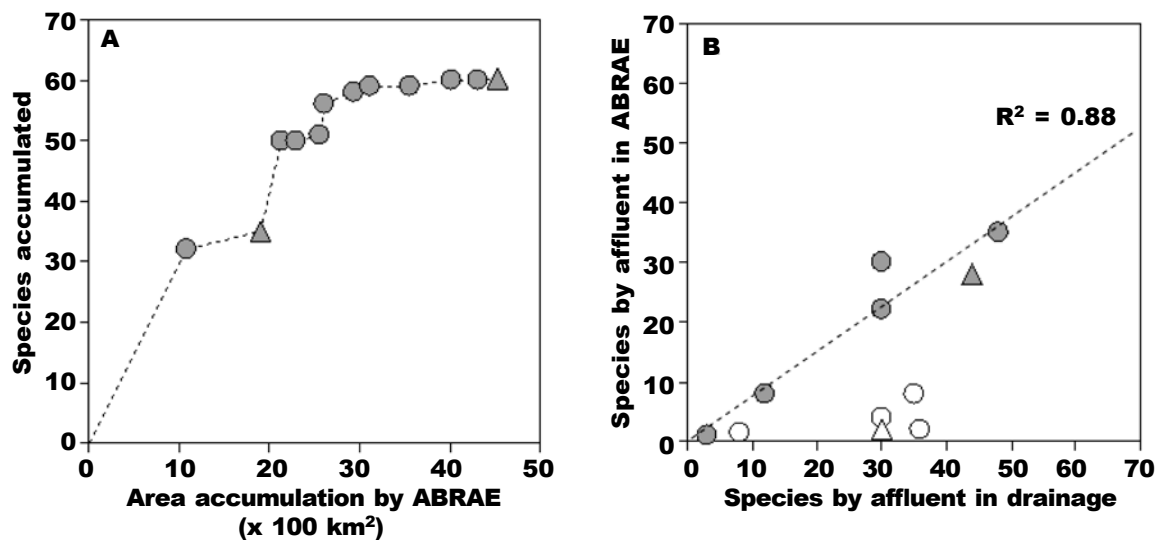


Fig. 3. A. Species and area accumulation in the ABRAE. Only national parks (●) and natural monuments (▲) were plotted against the cumulative number of fish species under protection. B. Relation between total number of species by tributary in the drainage as compared to those in an ABRAE in the same drainage. The broken line in B corresponds to a linear regression ( $R^2 = 0.88$ ) excluding very small ABRAE and/or those located in mountains ( $\Delta, \circ$ ).

Fig. 3. A. Acumulación de especies y áreas en las ABRAE. Sólo se consideraron los parques nacionales (●) y los monumentos naturales (▲) para construir la curva acumulativa de especies de peces protegidas. B. Relación entre el número total de especies por afluente en la cuenca y las especies de la misma cuenca que se encuentran dentro de una ABRAE. En B la línea punteada corresponde a una regresión lineal ( $R^2 = 0.88$ ) excluyendo las ABRAE muy pequeñas y/o localizadas en montañas ( $\Delta, \circ$ ).

et al., 2002), Venezuela (Rodríguez & Rojas-Suárez, 2008) and Brazil (Rosa & Lima, 2008). The pace and intensity of environmental perturbations and their effects on Neotropical fishes are still only partly evaluated and understood (Winemiller et al., 1996). The individual effects of multiple combined impacts acting on the same body of water are often difficult to assess and to replicate.

The richness and distribution of freshwater fishes needs to be taken into account to evaluate the utility of areas with special interest for the conservation of biodiversity. Dramatic variation detected in patterns of fish species richness, distribution and endemism associated with gradients of orography, physiographical units and hydrographic drainages indicates effects derive from many sources, such as altitude, latitude, and historical geological processes with associated ecological differences, all of which act at different scales.

For freshwater fish faunas of Caribbean slopes, regional boundaries generally coincide with the ecoregion for freshwater drainages of Caribbean South America and Trinidad proposed by Abell et al. (2008) and follow limits imposed by natural geographic characteristics of the region. However, these freshwater ecoregions did not discriminate local variability in patterns of species richness or distribution details for the species of fishes of the Caribbean provinces (fig. 4A). This also

occurred with most terrestrial ecoregions occurring in the WCP, such as xeric scrublands and montane forests of the Coastal range (Rodríguez et al., 2004) that cover fragments of the drainages where we found high species richness and endemism (fig. 4B). Similarly, the Tropical Andes hotspot (Myers et al., 2000) covers about 10% of the WCP, and was restricted to the high Andean and Coastal ranges where elevated endemism of terrestrial plants and animals has been reported, but it omits lowland floodplains where most fish species richness occurs.

Most ABRAE in the Western Caribbean Province of Venezuela do not adequately protect the variety of aquatic ecosystems present in the region, so they cannot guarantee the continuity of the hydrobiological processes required for their conservation. Most ABRAE cover highland, arid desert landscapes, or small fragments of tributaries and drainages. Although the streams protected in the highlands offer direct protection to the species that occur there and indirect help for species occurring downstream of protected areas, they cannot provide protection for impacts outside their boundaries. Such impacts are common downstream and include, for example, channelization, dredging, and water extraction, all of which severely degrade fluvial ecosystems and their fish faunas (Rodríguez-Olarte et al., 2006). Alteration

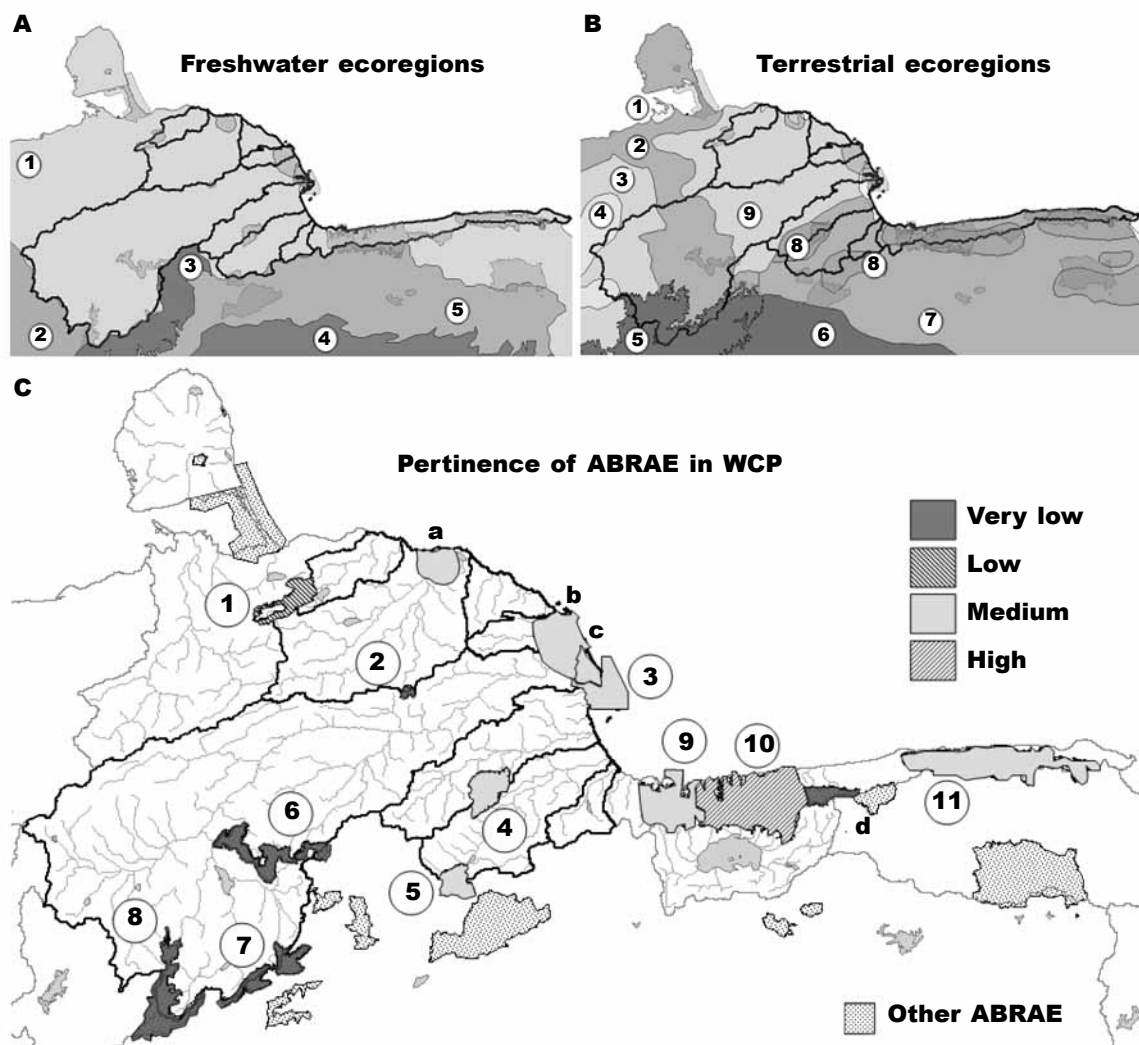


Fig. 4. Areas of interest for conservation associated with the Western Caribbean Province: A. Freshwater ecoregions (1. South America Caribbean Drainages–Trinidad; 2. Maracaibo; 3. Orinoco High Andes; 4. Orinoco Llanos; and 5. Orinoco Foothills); B. Terrestrial ecoregions (1. Coastal Venezuelan mangroves; 2. Paraganá xeric scrub; 3. Maracaibo dry forests; 4. Catatumbo moist forests; 5. Venezuelan Andes montane forest; 6. Llanos; 7. La Costa xeric scrublands; 8. Cordillera de La Costa montane forests; and 9. Lara–Falcón dry forests); the limits of the Tropical Andes hotspot are similar to terrestrial ecoregions 5 and 8; C. Protected areas ABRAE (1. Juan Cristótopmo Falcón; 2. Cueva de la Quebrada del Toro; 3. Morrocroy; 4. Yurubí; 5. Maria Lionza; 6. Saroche; 7. Yacambú; 8. Dinira; 9. San Esteban; 10. Henry Pittier; 11. Waraira Repano; 12. Hueque–Sauca [a], Tucurere [b] Golfete de Cuare [c] and Pico Codazzi [d]).

Fig. 4. Áreas de interés para la conservación asociadas a la Provincia Caribe Occidental: A. Ecorregiones de aguas continentales (1. Cuencas de Sudamérica al Caribe y Trinidad; 2. Maracaibo; 3. Altos Andes del Orinoco; 4. Llanos del Orinoco y 5. Piedemonte del Orinoco); B. Ecorregiones terrestres (1. Manglares costeros de Venezuela; 2. Matorral xerófilo de Paraganá; 3. Bosques secos de Maracaibo; 4. Bosques húmedos de Catatumbo; 5. Bosques montanos de los Andes de Venezuela; 6. Llanos; 7. Matorral xerófilo de la Cordillera de la Costa; 8. Bosques montanos de la Cordillera de la Costa y 9. Bosques secos de Lara–Falcón); los límites de los áreas clave de biodiversidad de los Andes Tropicales son similares a los de las ecorregiones 5 y 8; C. Áreas protegidas ABRAE (1. Juan Cristótopmo Falcón; 2. Cueva de la Quebrada del Toro; 3. Morrocroy; 4. Yurubí; 5. Maria Lionza; 6. Saroche; 7. Yacambú; 8. Dinira; 9. San Esteban; 10. Henry Pittier; 11. Waraira Repano; 12. Hueque–Sauca [a], Tucurere [b] Golfete de Cuare [c] y Pico Codazzi [d]).

of the natural flow regime affects the movements and migrations of fishes, which in turn greatly impacts local species richness gradients (Grossman et al., 2010). This could diminish the local conservation effects of a protected area, since fish diversity within its borders depends upon the conservation status of streams both upstream and downstream of their boundaries. Floodplain ABRAE are particularly vulnerable to disturbances that occur in headwaters. The existing protected areas in the study area offer protection to a little more than 80% of the fishes reported for the province. However, this is not an indication of high effectiveness of these ABRAE regarding the protection of freshwater fishes, and should be considered with caution. Existing ABRAE do offer partial protection to the fishes in the stream fragments they include (fig. 4C), but as we have shown, they do not effectively offer long term protection to the freshwater fishes of the region, and should be expanded or modified.

Areas with high priority for conservation identified in this study are offered only partial protection by existing ABRAE (e.g. Yurubí National Park, table 3) but this protection does not cover the physiographic units where highest fish species richness and endemism occur. Even so, the effectiveness of these ABRAE would be considerably increased if they were expanded to include the entire lengths of the tributaries, currently only partially protected within them. The scenario is different for mountain ABRAE because there is very low species diversity but high endemism. In these cases, protection of longer stretches would not necessarily increase the number of species under protection. These changes might occur in an ideal scenario, but the current condition of terrestrial ecosystems and established land-use patterns limit the implementation of protected areas for the conservation of aquatic resources. However, to better conserve even heavily used and limited water resources, we can promote management practices at a local scale such as by implementing reforestation of buffer strips or green belts along the shores (see Saunders et al., 2002), and concentrating efforts into smaller projects that focus on local objectives. This approach, as opposed to those that might require extensive areas set aside for conservation purposes, could be more successful in economically challenged areas with limited resources. We thus suggest that WCP programs that protect specific tributaries within aquatic refuge areas should extend the protective influence of already existing ABRAE as this would significantly improve protection of freshwater fish diversity.

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### References

- Abell, R., Blanch, S., Revenga, C. & Thieme, M., 2009. Conservation of aquatic ecosystems. In: *Encyclopedia of Inland Waters* (1): 249–258 (G. E. Likens, Eds.) Oxford: Elsevier.
- Abell, R., Thieme, M. L., Revenga, C., Bryer, M., Kotelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Balderas, S. C., Bussing, W., Stiassny, M. L. J., Skelton, P., Allen, G. R., Unmack, P., Naseka, A., Ng, R., Sindorf, N., Robertson, J., Armijo, E., Higgins, J. V., Heibel, T. J., Wikramanayake, E., Olson, D., López, H. L., Reis, R. E., Lundberg, J. G., Sabaj Pérez, M. H. & Petry, P., 2008. Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation. *BioScience*, 58(5): 403–414.
- Abellán, P., Sánchez-Fernández, D., Velasco, J. & Millán, A., 2005. Conservation of freshwater biodiversity: a comparison of different area selection methods. *Biodiversity and Conservation*, 14: 3457–3474.
- Barletta, M., Jaureguizar, A. J., Baigun, C., Fontoura, N. F., Agostinho, A. A., Almeida-Val, V., Val, A., Torres, R. A., Jimenes, L. F., Giarrizzo, T., Fabrè, N. N., Batista, V., Lasso, C., Taphorn, D. C., Costa, M. F., Chaves, P. T., Vieira, J. P. & Corrêa, M. F. M., 2010. Fish and aquatic habitat conservation in South America: a continental overview with emphasis on neotropical systems. *Journal of Fish Biology*, 76(9): 2118–2176.
- Bergerot, B., Lasne, E., Vigneron, T. & Laffaille, P., 2008. Prioritization of fish assemblages with a view to conservation and restoration on a large scale European basin, the Loire (France). *Biodiversity and Conservation*, 17: 2247–2262.
- Clarke, K. R. & Warwick, W. M., 1994. Similarity-based testing for community pattern: the 2-way layout with no replication. *Marine Biology*, 118: 167–176.
- Dufrène, M. & Legendre, P., 1997. Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecological Monographs*, 67(3): 345–366.
- Froese, R. & Pauly, D., 2010. *FishBase*. <http://www.fishbase.org>. Cited 15 Dic 2010.
- Grossman, G. D., Ratajczak, R. E., Farr, M. D., Wagner, C. M. & Petty, J. D., 2010. Why There Are Fewer Fish Upstream. *American Fisheries Society Symposium*, 73: 63–81.
- Herbert, M. E., McIntyre, P. B., Doran, P. J., Allan, J. D. & Abell, R., 2010. Terrestrial reserve networks do not adequately represent aquatic ecosystems. *Conservation Biology*, 24(4): 1002–1011.
- IUCN, 2001. *IUCN Red list categories and criteria: Version 3.1*. IUCN. Species Survival Commission.

- IUCN, Gland, Switzerland and Cambridge, UK.
- 2003. *Guidelines for application of IUCN red list criteria at regional Levels: Version 3.0*. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.
  - 2006. *Guidelines for using the IUCN Red List categories and criteria. Version 6.2*. Species Survival Commission, IUCN, Gland, Switzerland and Cambridge, UK.
- Lehner, B., Verdin, K. & Jarvis, A., 2006. Hydrosheds Technical Documentation. World Wildlife Fund US, Washington, DC. <http://hydrosheds.cr.usgs.gov>. Cited 20 Jan 2008.
- Lobón–Cerviá, J., 1991. Dinámica de poblaciones de peces. Pesca eléctrica y métodos de capturas sucesivas en la estima de abundancias. Monografías 3. Museo Nacional de Ciencias Naturales. CSIC, Madrid.
- McCune, B. & Mefford, M. J., 1999. PC–ORD. Multivariate Analysis of Ecological Data. Version 4.41. MjM Software, Gleneden Beach, Oregon, USA.
- Mojica, J., Castellanos, C., Usma, S. & Álvarez, R., 2002. Libro Rojo de las especies de peces dulceacuícolas de Colombia. Instituto de Ciencias Naturales Universidad Nacional de Colombia, Ministerio del Medio Ambiente, Bogotá, Colombia.
- Myers, N., Mittermeier, R., Mittermeier, C., da Fonseca, G. & Kent, J., 2000. Biodiversity hotspots for conservation priorities. *Nature*, 403: 853–858.
- Nogueira, C., Backup, P. A., Menezes, N. A., Oyakawa, O. T., Kasecker, T. P., Ramos Neto, M. B. & C. da Silva. J. M., 2010. Restricted–range fishes and the conservation of Brazilian freshwaters. *PLoS ONE*, 5(6): e11390. doi:10.1371/journal.pone.0011390.
- Olson, D. M. & Dinerstein, E., 2002. The Global 200: priority ecoregions for global conservation. *Annals of the Missouri Botanical Garden*, 89: 199–224.
- Reis, R. E., Kullander, S. O. & Ferraris, C. J., 2003. Check list of the freshwater fishes of South and Central America. EDIPUCRS, Porto Alegre, Brasil.
- Rodríguez, J. P., Lazo, R., Solórzano, L. A. & Rojas–Suárez, F., 2004. Cartografía digital básica de las Áreas Naturales Protegidas de Venezuela: Parques Nacionales, Monumentos Naturales, Refugios de Fauna, Reservas de Fauna y Reservas de Biósfera. Versión 1.0, CD ROM y en–línea. Centro Internacional de Ecología Tropical (CIET), Instituto Venezolano de Investigaciones Científicas (IVIC), Conservación Internacional Venezuela, UNESCO y Oficina Nacional de Diversidad Biológica del Ministerio del Ambiente y de los Recursos Naturales (MARN). Caracas, Venezuela. <http://ecosig.ivic.ve>. Cited 20 Jan 2008.
- Rodríguez, J. P. & Rojas–Suárez, F., 2008. Libro Rojo de la Fauna Venezolana. Tercera Edición. Provita y Shell Venezuela, S. A., Caracas, Venezuela.
- Rodríguez–Olarde, D., Amaro, A., Coronel, J. L. & Taphorn, D. C., 2006. Integrity of fluvial fish communities is subject to environmental gradients in mountain streams, Sierra de Aroa, north Caribbean coast, Venezuela. *Neotropical Ichthyology*, 4(3): 319–328.
- Rodríguez–Olarde, D., Coronel, J. L., Taphorn, D. C. & Amaro, A., 2007. Los Peces del río Tocuyo, Vertiente del Caribe, Venezuela: un Análisis Preliminar para su conservación. *Memoria de la Fundación La Salle de Ciencias Naturales*, 165: 45–72.
- Rodríguez–Olarde, D., Taphorn, D. C. & Lobón–Cerviá, J., 2009. Patterns of Freshwater Fishes of the Caribbean Versant of Venezuela. *International Review of Hydrobiology*, 94(1): 67–90.
- Rosa, R. S. & Lima, F. C. T., 2008. Os Peixes Brasileiros Ameaçados de Extinção. In: *Livro Vermelho da fauna brasileira ameaçada de extinção*. Volume 2: 9–285 (A. B. M. Machado, G. M. Drummond & A. P. Paglia, Eds.). 1st edition. Brasília, DF: MMA; Belo Horizonte, MG: Fundação Biodiversitas.
- Saunders, D. L., Meeuwig, J. J. & Vincent, C. J., 2002. Freshwater protected areas: strategies for conservation. *Conservation Biology*, 16: 30–41.
- Whittaker, R. J. & Fernández–Palacios, J. M., 2007. *Island biogeography: ecology, evolution, and conservation*, 2nd edition. Oxford University Press, Oxford.
- Winemiller, K., Marrero, C. & D. Taphorn. 1996. Perturbaciones causadas por el hombre a las poblaciones de peces de los llanos y del piedemonte andino de Venezuela. *BioLlania*, 12: 13–48.