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Effects of the freshwater aquarium trade on wild fish populations in differentially-fished areas of the Peruvian Amazon

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Base-line data were collected to examine the possible effects of the aquarium trade on Amazon fish populations in differentially-fished locations in the Departmento of Loreto, Peru. Fish abundance, species diversity (richness) and biomass were quantified at three locations with differential fishing pressure, including the Rio Nanay (high pressure), Rio Apayacu and Rio Arambassa (medium) and Rio Yanayacu –Pacaya-Samiria National Reserve (low). Seining results indicated that the location with the highest fishing pressure had reduced fish abundance, species diversity and biomass compared to the other locations. A similar trend was seen using minnow traps. There was no significant difference in abundance, diversity and biomass between the medium and low fishing pressure locations. Habitat differences (pH and conductivity) among the three locations accounted for <13% of the observed variation, and thus it seemed possible that some of the decline in the Rio Nanay location could be tentatively attributed to increased fishing pressure. Although effects of pollution and habitat alteration could not be ruled out, this is one of the first studies to provide quantitative data on the effect of the freshwater aquarium trade on wild fish populations. While results suggest success in the protection of fishes for the aquarium trade in Pacaya-Samiria National Reserve, it also may be sustainable to establish limited levels of fishing, as was found in the medium fishing pressure locations, in order to promote economic opportunities and incentives for habitat preservation for indigenous communities.

Key words: Amazon River Basin; aquarium trade; artisanal; fisheries; ornamental; overfishing.

INTRODUCTION

The aquarium fish trade has expanded rapidly over the past 50 years, with many millions of hobbyists worldwide (Davenport, 1996). The popularity of fish

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keeping is evidenced by the estimated 10% of U.S.A. and 13% of U.K. households which keep fishes as pets (Davenport, 1996). The FAO statistics from 1990 show that major importers of home aquarium fishes are Europe, North America and Asia, with, for example, >1000 species of tropical marine and freshwater fishes imported into the U.K. annually (Davenport, 1996).

Considerable attention has been given to the impact of the trade on coral reef fishes (Kolm & Berglund, 2003; Tissot & Hallacher, 2003) since most marine fishes are 'wild-caught' (Tissot & Hallacher, 2003) and because of high impact collecting methods such as blast fishing and cyanide use. In contrast, little attention has been paid to the freshwater trade, although the exceptions include Crampton (1999), Chao (2001) and unpubl. data, since a majority of freshwater aquarium fishes (>90%) are raised in captivity (Andrews, 1990). Estimates from customs records in the U.K., however, indicate that only 6·2% (by value) of live fish imports were tropical marine (Davenport, 1996). Similarly only 4% by volume of aquarium fishes imported into the U.S.A. were marine (*c*. 8 million fishes) (Basleer, 1994). Export estimates from Peru indicate that 11 million freshwater aquarium fishes were exported in 1992 (J. Soregui Vargas & V.H. Montreuil Frias, unpubl. data), and Peru is not even in the top 10 list of source countries (by value) exporting fishes to the European Union (Davenport, 1996). Estimates of annual Brazilian freshwater fish exports range from 16·5 to 22 million (Andrews, 1990; Leite & Zuanon, 1993). These exports represent wild-caught fishes, since there is no commercial cultivation of aquarium fishes in the Amazon (Crampton, 1999). Although statistics for the aquarium trade are often non-existent or incomplete, it is probable that numbers of wild-caught freshwater fishes in the trade far exceeds wild-caught marine fishes. The ecological impacts of the freshwater fish trade in the Amazon thus warrants closer examination.

The majority of wild-caught aquarium fishes from the Amazon basin are exported from Brazil, Colombia and Peru. Most of these fishes, such as the popular neon tetra *Paracheirodon innesi* (Myers), arahuana *Osteoglossum bicirrhosum* (Cuvier), corydoras catfishes *Corydoras* spp., suckermouth catfishes *Hypostomus* spp., hatchet fishes *Carnegiella* spp. and cichlids *Apistogramma* spp. are purchased by home-hobbyists. The study focused on the species-diverse aquarium fish trade in Peru, where *c*. 60% of the trade is comprised of 10 species, with no single species comprising >15% of the annual trade (Hanek, 1982; Tello & Canepa, 1991). Well over 300 species are probably exported from the Peruvian Amazon, a single Iquitos exporter listed >270 fish species in stock in April 2005 (Acuario Panduro, 2005). In contrast, the Brazilian trade centred in Manaus is comprised of *c*. 80% cardinal tetra *Paracheirodon axelrodi* (Schultz) (Chao, 2001). The centre of aquarium fish export in Peru is Iquitos, where the trade has been active since the 1950s when there were 13 registered commercial aquarium dealers which increased to 32 by 1996 (Tello & Canepa, 1991; J. Soregui Vargas & V.H. Montreuil Frias, unpubl. data). Estimates of fishes exported between 1988 and 1997 range from a low of 6·4 million in 1990 to a high of 17·9 million in 1994 (V.H. Soregui Vargas & V.H. Montreuil Frias, unpubl. data). While the economic impact of the trade on local communities has yet to be determined, it is estimated that some 3000 families make a living from and 100000 persons benefit economically from the trade, often in villages where few other economic opportunities may be available.

Wild-caught aquarium fishes are potentially one of the few sustainable resources in the Amazon basin. Theoretically, life-history traits such as short life span and high egg production, plus low-impact collecting methods and seasonal extremes in rainfall may limit the exploitation of this resource (Andrews, 1990). Claims that the Amazon aquarium fishery is sustainable (Chao, 2001), however, have not been supported by standardized ecological sampling, and anecdotal reports from fishers in the Peruvian Amazon indicate that the number of species caught is declining and fishers have to travel further to catch the same numbers of fishes (S. Tello, pers. comm.). Some populations of the high-value discus *Symphysodon aequifasciatus* Pellegrin in Brazil have apparently collapsed due to over-collection (Crampton, 1999) and data from a recent study on the Rio Nanay in Peru indicates that areas sampled closer to Iquitos have reduced abundance and species diversity compared to areas further upstream on the same river (unpubl. data). While collections have been made of Amazonian fishes for taxonomic studies, there are few standardized, quantitative datasets on the abundance and distribution of Amazonian aquarium fish species and the ecological impact of the fishery is largely unknown (Bayley & Petrere, 1989). The purpose of this study was to establish base-line data on fish populations and to evaluate potential impacts of the Amazon aquarium fish trade in three differentially-fished areas of Peru. It was predicted that heavy fishing pressure locations on the Rio Nanay would have reduced fish abundance and species diversity (richness) compared to a location in Pacaya-Samiria National Reserve, where fishing is strictly limited, and to Amazon tributaries downriver of Iquitos where only a few families are known to fish for the aquarium trade.

MATERIALS AND METHODS

STUDY LOCATIONS

Data were collected from three locations of differing fishing pressure in the Peruvian Amazon during low-water (August to September) of 2001 (Table I). The Rio Nanay is the location with heavy fishing pressure for ornamentals ('high'), while the Rio Yanayacu in Pacaya-Samiria National Reserve represents low fishing pressure ('low'). The intermediate fishing pressure location ('medium') is downstream of Iquitos and included sites on the Rio Apayacu (Quebradas Sabalillo and Yanayacu) and the Rio Arambassa. The Rio Nanay has historically experienced significant fishing for the aquarium trade due to its proximity to the city of Iquitos, and it is one of 15 major aquarium fish collection sites in Peru (J. Soregui Vargas & V.H. Montreuil Frias, unpubl. data). Only now that motorboats are used by wealthier collectors have further reaches of the upper Amazon basin become open to the aquarium fishery. The medium location in this study is still several hours away from Iquitos by small motorboat, a factor that keeps the collecting effort fairly low. It was chosen for its intermediate distance from Iquitos and because only a few families are known to participate in aquarium fish collecting. The Pacaya-Samiria National Reserve location (low) is many hours to several days travel by boat from Iquitos (depending on water levels), and is not a commercially feasible collection location for most aquarium fishes, except for the high-value arahuana. The reserve is a 20 243 km^2 area established in 1982 and managed by the National Institute of Natural Resources (INRENA) for conservation and sustainable use. The Peruvian conservation organization ProNaturaleza works with the village of Manco Capac (closest to Lago El Dorado) to produce a fishery management plan for the area. A fishing co-op manages harvests of 'paiche' *Arapaima gigas* (Schinz) for food and arahuana for the aquarium

TABLE I. Sampling locations

Fishing pressure	Nearest village	River description	Latitude and longitude
Low	Manco Capac	Rio Maranon tributary-Quebrada Yanayacu - Quebrada Llanchama	S 5° 05·584′ W 74° 21·396′
	Manco Capac	Maranon River tributary- Quebrada Yanayacu - near Lago El Dorado	S 5° 03·807′ W 74° 18·321′
	Manco Capac	Maranon River tributary- Quebrada Yanayacu - near Lago El Dorado	S 5° 03·549′ W 74° 17·198′
	Manco Capac	Maranon River tributary- Quebrada Yanayacu - Quebrada Llanchama	S 5° 05·869′ W 74° 20·792′
	Manco Capac	Rio Maranon tributary- Quebrada Yanayacu - Anuncho Cano	S 5° 05·713′ W 74° 18·936′
	Manco Capac	Maranon River- Quebrada Yanayacu - near Achung Trail to Manco Capac	S 5° 03·927′ W 74° 13·907′
Medium	Yanashi	Amazon River tributary- Quebrada Arambassa	S 3° 35·437′ W 72° 18·019′
	Arambassa/ Esperanza	Amazon River tributary- Quebrada Arambassa	S 3° 35·382′ W 72° 25·258′
	Sabalillo	Rio Apayacu tributary- Quebrada Sabalillo	S 3° 21·487′ W 72° 17·593′
	Sabalillo	Rio Apayacu tributary- Quebrada Sabalillo	S 3° 21·350′ W 72° 16·110′
	Yanayacu	Rio Apayacu tributary- Quebrada Yanayacu	S 3° 29·136′ W 72° 15·368′
	Yanayacu	Rio Apayacu tributary- Quebrada Yanayacu	S 3° 29·052′ W 72° 15·421′
High	Diamante Azul	Rio Nanay tributary- Quebrada Puynsicki	S 3° 55·157′ W 73° 47·436′
	Diamante Azul	Rio Nanay tributary	S 3° 54·569′ W 73° 45·496′
	Santa Clara	Rio Nanay tributary	S 3° 47·241′ W 73° 20·589′
	San Pedro/ Santa Clara	Rio Nanay tributary- Quebrada Tres Unidos	S 3° 45·859′ W 73° 19·565′
	Bella Vista	Rio Nanay tributary- Rio Momon tributary	S 3° 41·063′ W 73° 16·083′
	Morona Cocha	Rio Nanay tributary- Morona Cocha	S 3° 43·530′ W 73° 16·570

trade. No other aquarium fishes are regularly harvested, however, so this site was considered a low fishing pressure location.

At all three sites, low water meant that water had receded from the floodplain and fishes were concentrated in the remaining deeper channels. These channels exhibited a mixture of bare or lightly vegetated river bank, and brushy and heavily vegetated areas where overhanging or emergent vegetation provided moderate to dense cover. Floating aquatic vegetation and dense leaf litter occurred at low frequency in all three sites, while submerged 'snags', logs and other woody obstructions were common to all sites. Collecting locations nearest Iquitos on the Rio Nanay (high) had experienced various degrees of tree canopy removal (*e.g.* for timber and building materials), but river-side brush and second growth remained dense. The medium site experienced some selective logging disturbance in the early-mid 1990s, with subsequent building material removal by local people (D. Graham, pers. obs.), but also exhibited dense riverside vegetation. The low fishing pressure site in the Pacaya-Samiria Reserve has not experienced logging or tree cover removal. The topography of the floodplain at study sites there, however, is such that sampled areas were similar in overall tree and brush cover to the other two sites. No collecting locations were adjacent to, or in the immediate vicinity of denuded areas (*e.g.* pastures, agricultural fields and villages).

FIELD SAMPLING

Standardized fish sampling facilitated comparisons among the three locations with different fishing pressure. Sampling incorporated both passive and active gear to sample a range of fish sizes and to minimize the impact of behavioural gear bias. Gee minnow traps ($22{\cdot}8 \times 44{\cdot}5$ cm) were set at 5 m intervals in two 30 m long transects at each site, with five traps per transect. Trap transects at each site were separated by >500 m. Traps with two different mesh and entrance opening sizes were used in alternating sequence to collect a range of species sizes: (1) minnow and crawfish trap, 5·7 cm opening and 0·64 cm mesh ($n = 4$ per site) and (2) minnow and exotic trap, 2·5 cm opening and 0·32 cm mesh ($n = 6$ per site). Each trap was baited with commercially available dog food. Minnow traps worked very well in all areas except for the low fishing pressure location (Pacaya-Samiria National Reserve) where their use was abandoned due to trap destruction by abundant large caiman (*Caiman crocodilus* and *Melanosuchus niger*). Small seines ($2{\cdot}1 \times 1{\cdot}35$ m, 3 mm mesh) thus became the predominant sampling method in all locations, used in 10 m long seine hauls parallel to the riverbank. This beach seine method has been shown to be as effective as other seining techniques (Petry *et al.*, 2003). The small mesh-size was needed in order to capture the small trade species (*i.e.* characids). A short seine length, however, was necessary; otherwise the net pushed too much water ahead of the sampling path and became entangled in logs and twigs. To ensure sufficient sampling of an area, seine hauls were replicated. The first seine haul began at the end of each trap transect, with subsequent seine hauls at 100 m intervals upstream along the riverbank ($n = 8$ seine hauls per site). No data are available on the movement patterns of aquarium species but it is believed that the seine samples represent independent replicates since the sampling team walked overland and away from the river bank when moving between adjacent seine haul sites to avoid driving fishes from one site to the next. Any highly mobile (fast swimming) species that may have been able to quickly move between adjacent seining sites are also species unlikely to be captured in a small seine (easily swimming faster than a seine can be pulled). Seine hauls avoided areas with dense brush or concentrations of 'snags' and debris where net entanglement would have permitted the escape of most fishes. A concerted effort was made to haul seines at a constant steady rate at each sampling site to reduce potential inter-seine sampling biases.

Prior to each seine sample, basic habitat measurements were taken (temperature, pH, dissolved oxygen, conductivity and water depth) to account for possible spatial variation in the rivers. Temperature, pH and conductivity were recorded using the Oakton© pH/CON 10 pH/Conductivity/° C meter. Dissolved oxygen was measured using an YSI 55 oxygen meter. Measurements were only taken at the first seine location per site for the medium fishing pressure location. Water depth was measured for each minnow trap, and water chemistry values for the first seine haul at each site were expected to correspond to the adjacent trap transect.

All fishes of interest to the trade were preserved in 10% formalin. Field identification is currently impossible for many Amazon ornamental fishes, due to the lack of field keys, the need to discern complex characters requiring dissecting or microscopic examination, and the lack of distinctive colour patterns (*e.g.* non-descript characids or juvenile fishes).

Fishes were euthanized with an overdose of MS222 prior to preservation. At each site and for each sampling method, the number of individuals of each species was determined, and the species diversity (richness) and biomass were measured. Rigorous adherence to the sampling protocol was followed to facilitate statistical comparisons among the three areas with different levels of fishing pressure, reducing the impact of inherent variability that occurs in all natural systems. The collecting protocol, however, probably underestimated total species richness. Another collecting method such as rotenone would increase richness values, but it is impossible to standardize this method in the field, making analysis difficult (Galacatos *et al.*, 1996). The methods used here are considered most appropriate for an ecological study, and the species richness values are useful for comparative purposes.

Prior to preservation, fishes were weighed collectively per seine haul or trap to estimate fish biomass. This measurement was included to differentiate sites producing characids with small mass *v.* catfishes or other species with larger mass. Unfortunately, the field scale was unavailable for sampling efforts in the medium fishing pressure sites. Fishes from these sites were weighed *c.* 1 month after preservation in 10% formalin. Previous studies have shown that formalin preservation can cause tissue mass to change, and thus a sub-set of samples from other sites was also weighed after formalin preservation. A regression equation was computed between the 'fresh' and 'formalin' masses, and the fresh masses for the medium fishing pressure sites were backcalculated. The equation used for the seine samples was $y = 1{\cdot}0107x - 3{\cdot}297$ ($F_{1,30}$, $P < 0{\cdot}001$, $r^2 = 0{\cdot}983$), where x is the mass after storage in 10% formalin and y is the fresh mass. The equation used for the small-mesh minnow trap samples was $y = 0{\cdot}9782x + 0{\cdot}3698$ ($F_{1,10}$, $P < 0{\cdot}001$, $r^2 = 0{\cdot}992$). The equation used for the large-mesh minnow trap samples was $y = 0{\cdot}8732x + 4{\cdot}035$ ($F_{1,2}$, $P < 0{\cdot}001$, $r^2 = 0{\cdot}998$).

Fish collections were divided between authors (Ortega, Sanchez and Gerstner), with fishes identified by each deposited in the Museo de Historia Natural (Lima, Peru), the Instituto de Investigaciones de la Amazonia Peruana (Iquitos, Peru) and the Field Museum of Natural History (Chicago, U.S.A.) respectively. Identifications were compared among authors to assure consistency.

ANALYSIS

Data were analysed using SYSTAT 10.2 statistical software. To determine whether fishing pressure was having an impact on the dependent variables (fish abundance, species diversity or biomass) for the seine data, three one-way ANOVA were performed (Neter *et al.*, 1996). Tukey HSD multiple comparison tests were used to make comparisons among fishing pressure levels. Data were transformed using a $\log_{10}(x + 1)$ to avoid problems with zeros in the data and to meet assumptions of normality (Sokal & Rohlf, 1969).

Data from the minnow traps were standardized per hour fished, resulting in a catch per unit effort measurement (CPUE). Assumptions for a *t*-test could not be met, even with $\log_{10}(x + 1)$ transformations. Thus, a non-parametric Mann–Whitney *U*-test was used to test for differences between the two fishing pressure locations (high and medium) using the trap data.

To examine the possible impact of habitat variables (pH, conductivity, dissolved oxygen, temperature and depth) on the dependent variables (fish abundance, species diversity and biomass) in the seine samples, the data reduction technique of principle components analysis (PCA) was used (correlation matrix, minimum eigenvalue = 1·0 and no rotation). The analysis produced a concise factor score to summarize the habitat variables per site. These factor scores were plotted against the dependent variables, and then used in three simple linear regressions to determine the degree of association. Only the high and low sampling areas had complete habitat data, so the medium sites were excluded from this analysis. A multiple linear regression using all of the habitat variables was not appropriate since most were moderately correlated.

RESULTS

A total of 7928 fishes were collected representing 18 families (Anostomidae, Apteronotidae, Aspredinidae, Auchenipteridae, Callichthyidae, Characidae, Chilodontidae, Cichlidae, Curimatidae, Doradidae, Engraulidae, Erythrinidae, Gasteropelecidae, Hypopomidae, Lebiasinidae, Loricariidae, Rivulidae and Trichomycteridae) (Reis *et al*., 2003). Virtually all species collected were considered part of the freshwater aquarium trade (J. Soregui Vargas & V.H. Montreuil Frias, unpubl. data), except for the few individuals and species from the Engraulidae and Trichomycteridae.

The seine, small-mesh trap and large-mesh trap data were analysed separately in order to examine the impact of fishing pressure. For the seine, the ANOVA results indicated a highly significant location effect (low, medium, high fishing pressure locations) on fish abundance ($F_{2,141}$, $P < 0{\cdot}001$), species diversity ($F_{2,141}$, $P < 0{\cdot}001$), and fish biomass ($F_{2,141}$, $P < 0{\cdot}001$). The mean fish abundance (individuals per seine haul) for the high fishing pressure location (Rio Nanay) was statistically significantly lower ($8{\cdot}3 \pm 4{\cdot}2$, mean $\pm$ 95% CI) than the medium ($22{\cdot}6 \pm 9{\cdot}6$) or low ($22{\cdot}6 \pm 7{\cdot}6$) fishing pressure locations (both, $P \leq 0{\cdot}001$; Fig. 1). There were no significant differences in abundance between the medium and low fishing pressure locations ($P > 0{\cdot}05$). Similarly, the mean species diversity (species per seine haul) for the high fishing pressure location (Rio Nanay) was statistically significantly lower ($2{\cdot}2 \pm 0{\cdot}69$) than the medium ($4{\cdot}6 \pm 0{\cdot}86$) or low ($5{\cdot}1 \pm 1{\cdot}2$) fishing pressure locations (both, $P < 0{\cdot}001$; Fig. 1). There were no significant differences in species diversity between the medium and low fishing pressure locations ($P > 0{\cdot}05$). Finally, the mean fish biomass for the high fishing pressure location (Rio Nanay) was statistically significantly lower ($6{\cdot}1 \pm 2{\cdot}6$ g) than the medium ($30{\cdot}7 \pm 14{\cdot}4$ g; $P = 0{\cdot}028$) or low ($40{\cdot}2 \pm 18{\cdot}7$ g; $P = 0{\cdot}001$) fishing pressure locations ($P \pm 0{\cdot}001$; Fig. 1). There were no significant differences in biomass between the medium and low fishing pressure locations ($P > 0{\cdot}05$).

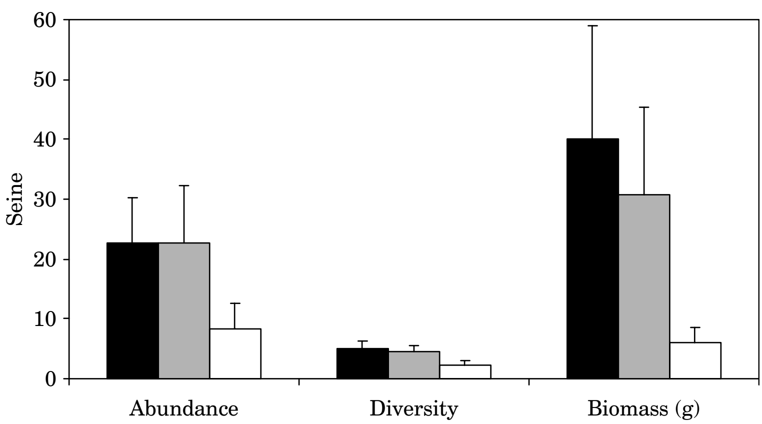

FIG. 1. Fish abundance, species diversity (richness) and fish biomass per seine haul at three locations experiencing low (■), medium (■) and high (□) fishing pressure. The high fishing pressure location showed significantly lower abundance, diversity and biomass ($P < 0{\cdot}05$) compared to the other locations. Values are means + 95% CI.

The impact of location (low, medium, high fishing pressure locations) on the fishery variables was also evident using the minnow trap data. For the large mesh traps, significant differences were seen between the medium and high fishing pressure locations for abundance h^{-1} fished (Mann–Whitney *U*-test, $P = 0{\cdot}033$), species diversity h^{-1} fished (Mann–Whitney *U*-test, $P = 0{\cdot}027$) and biomass h^{-1} fished (Mann–Whitney *U*-test, $P = 0{\cdot}024$) (Fig. 2). Data from the small mesh traps showed that species diversity h^{-1} fished was statistically significantly different between medium and high fishing pressure locations (Mann–Whitney *U*-test, $P = 0{\cdot}046$), as was biomass h^{-1} fished (Mann–whitney *U*-test, $P = 0{\cdot}035$) (Fig. 3). There was no statistically significant difference in fish abundance, however, perhaps due to increased variability. It is unclear as to whether this indicates that the medium location was also facing overfishing pressure or if the high location was not as overfished, since the traps could not be used in the low fishing pressure site due to caiman.

PCA of the habitat data produced results that explained 47% of the variation with the first factor score, while the second factor score explained 26% of the variation. The first factor score was plotted against the $\log_{10}(x + 1)$ values of each dependent fishery value (Fig. 4). From these plots it became evident that the two different fishing pressure locations (high and low) had different habitat values. Summary data confirmed that most of the differences were related to differences in pH and conductivity, with the high fishing pressure sites also having the lowest pH and conductivity values. Low conductivity and pH, evident in blackwater rivers, has been linked to low productivity in Amazon River systems and may be an explanation for lowered fish abundance in those rivers (Smith, 1981). Species diversity, however, should not be impacted, since blackwater rivers have high species diversity. Conductivity values were 12·9 1·3 ± μS l^{-1} (mean ± 95% CI) for the high location ($n = 48$), 63·7 ± 55·9 μS l^{-1} in the medium location ($n = 6$) and 147·7 ± 10·1 μS l^{-1} in the low location ($n = 48$),

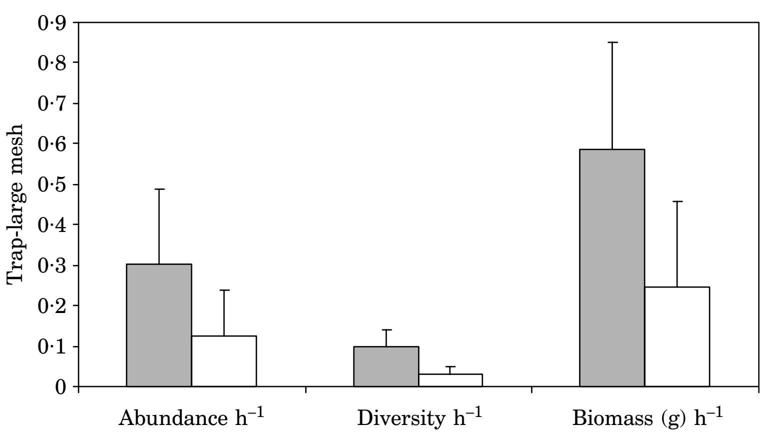

FIG. 2. Fish abundance, species diversity (richness) and fish biomass per large mesh minnow traps (standardized per hour fished), in the two locations that experienced medium (■) and high (□) fishing pressure. The low fishing pressure location was not sampled with traps due to presence of large caiman. The high fishing pressure location showed significantly lower fish abundance, species diversity and fish biomass ($P < 0{\cdot}05$) compared to the medium location. Values are means + 95% CI.

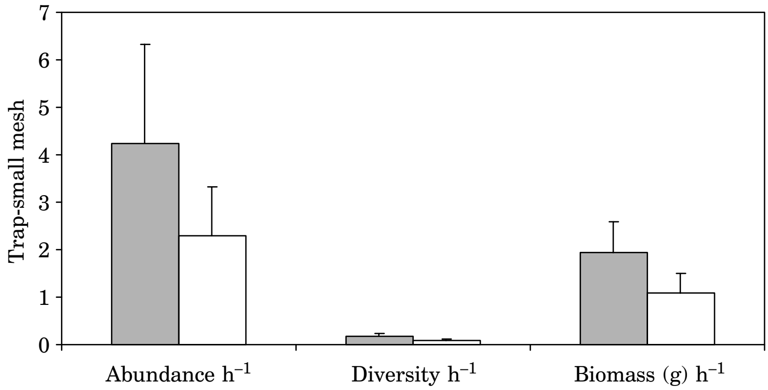

FIG. 3. Fish abundance, species diversity (richness) and fish biomass per small mesh minnow traps (standardized per hour fished), in two locations that experienced medium (■) and high (□) fishing pressure. The low fishing pressure location was not sampled with traps due to presence of large caiman. The high fishing pressure location showed significantly lower species diversity and biomass ($P < 0{\cdot}05$) compared to the medium location, whereas fish abundance showed no statistically significant differences. Values are means + 95% CI.

while pH values were 5·1 ± 0·2 in the high location, 6·1 ± 0·8 in the medium location and 7·4 ± 0·1 in the low location. Depth values were 0·9 ± 0·1 m in the high location, 0·5 ± 0·1 m in the medium location and 0·6 ± 0·1 m in the low location. Dissolved oxygen values were 5·0 ± 0·4 mg l^{-1} in the high location, 3·8 ± 2·2 mg l^{-1} in the medium location and 4·3 ± 0·8 mg l^{-1} in the low location. Finally, temperature values were 28·5 ± 0·8° C in the high location, 26·6 ± 0·4° C in the medium location and 30·5 ± 0·6° C in the low location.

In order to determine whether these differences could have an impact on the fishery variables and thus the conclusions, it was necessary to determine whether there was an association between each. From the scatterplots, no obvious higher order pattern in the data emerged and thus a non-linear regression did not seem appropriate, especially without any biological basis for the choice of the equation. Since the data had been $\log_{10}$ transformed, which tends to create linear relationships, simple linear regression was chosen to examine the strength of each relationship. While all three regression equations showed a statistically significant relationship ($P < 0{\cdot}05$), none exhibited a very good fit (all $r^2 < 0{\cdot}125$). In particular, factor 1 score exhibited a significant, but poor fit with fish abundance ($F_{1,90}$, $P < 0{\cdot}008$, $r^2 = 0{\cdot}076$), species diversity ($F_{1,90}$, $P < 0{\cdot}002$; $r^2 = 0{\cdot}102$) and biomass ($F_{1,90}$, $P < 0{\cdot}001$, $r^2 = 0{\cdot}125$). Regressions with the second factor score produced similar results. The lack of fit of the model could be partially explained by lack of biological basis for a linear relationship between, for example, abundance and temperature. It is likely that some intermediate temperature would produce the greatest abundance of fishes. This pattern, however, was probably smoothed by the $\log_{10}$ transformation and thus the linear model still seems like the best default choice.

Although some of the differences among fishing pressure locations could thus be attributed to habitat differences, the strength of the regression relationship was not high for any of the models, explaining at most 13% of the variation

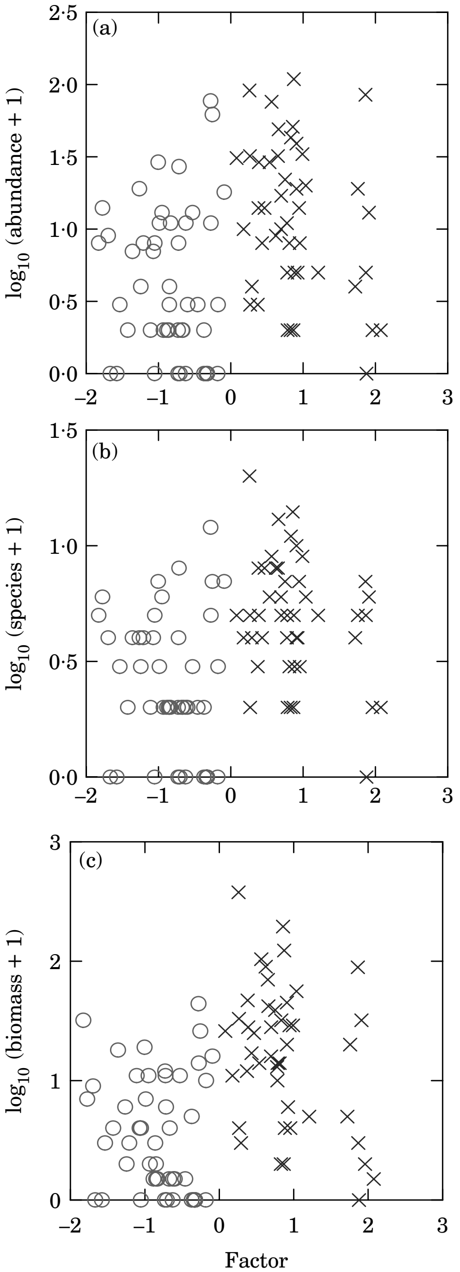

FIG. 4. Scatterplots of three $\log_{10}(x + 1)$ transformed fishery independent variables (a) abundance, (b) diversity and (c) biomass with PCA factor 1 scores of five habitat variables (depth, temperature, conductivity, pH and dissolved oxygen) at two locations with different fishing pressures: high (○) and low (×).

seen. Similarly, habitat differences would not be expected to impact species diversity, yet the data show reduced diversity in the high fishing pressure locations. In addition, a more specific examination of the data within rivers indicated that two sites furthest from Iquitos on the Rio Nanay (high) had some of the highest abundance, diversity and biomass mean values (unpubl. data), contrary to what would be expected for their habitat measurements (low conductivity and low pH usually correlating with low productivity). Thus, the habitat data do not appear to be the only variables driving the fishery dependent variable results. Therefore, although habitat variability could be partially responsible for the significant differences in fish abundance, diversity and biomass among the locations differing in fishing pressure, significant variation still remains, which thus could be at least partially attributed to fishing pressure. This study represents a first step in quantifying the status of wild populations of freshwater aquarium trade fishes, however, it is clear that more data are needed to identify all of the factors contributing to population variability.

DISCUSSION

The results from the seine sampling indicated that aquarium fish populations in the Rio Nanay have reduced abundance, species diversity and biomass compared to populations both in Pacaya-Samiria National Reserve and in locations sampled on Amazon tributaries downriver from Iquitos. The original hypothesis was that these differences were due to higher fishing pressure on the Rio Nanay, however, other explanations are possible.

Local deforestation and floodplain habitat alteration could also have influenced fish abundance, diversity and biomass. Canopy cover has been shown to play an important part in fish community distributions (Marsh-Matthews & Matthews, 2000), and tall tree cover was lacking in many high fishing pressure sites, probably due to deforestation. Results of studies on the impact of deforestation from Central and South America, however, have been equivocal (Burcham, 1988; Lyons *et al*., 1995). In a riverine system closely resembling those studied here, Bojsen & Barriga (2002) found that fish abundance increased with deforestation in an Ecuadorian Amazon stream, and species richness was not impacted. Canopy removal might impact fish populations through physical means (*e.g*. increased water temperatures and higher turbidity from riverbank erosion) or through the reduction of resources important to fishes (*e.g*. fallen canopy fruits, plant materials and insects). Such impacts could potentially be counterbalanced by greater productivity by submerged and floating macrophytes, perhaps explaining the equivocal results of previous studies. The overall area of floodplain available to fishes in each of the study areas also remains an unknown factor. If the amount of dry-season habitat (*i.e*. the deeper channels that retain water) is critical to fish population dynamics, then the three study areas are probably roughly equivalent in the availability of suitable habitat. On the other hand, if the total area of wet-season habitat (*i.e*. the entire floodplain) is most important in regulating fish populations, then the high and medium sites would be roughly equivalent in habitat availability, whereas the low site probably has a more expansive floodplain area per unit of dry-season river channel.

Pollution is also a potential problem in the aquatic habitats of Peru. Many communities lack adequate sanitary facilities and raw sewage may be dumped into the rivers. Sampled 'high' sites on the Rio Nanay closest to Iquitos were most likely to be affected by sewage, though other more remote locations may have also been impacted to a lesser extent. The Rio Nanay has also been the site of gold dredging in recent years (H. Sanchez, pers. obs.), probably contributing to mercury contamination and siltation. Gold mining siltation has been shown to lower species richness and food fish biomass in South American streams (Mol & Ouboter, 2004). Gold dredging in the Rio Nanay, however, takes place in the main channel, not the tributaries which may be buffered from impacts. Therefore, it would seem unlikely that the effects of pollution and gold mining would be able to account for a large portion of the variation among the three locations. Evaluating the possible impacts of pollution are beyond the scope of this paper, however, this factor cannot be ruled out as a cause of fish declines.

Despite attempts to select rivers for this study that were generally similar in size and flow rates, rivers in the upper Amazon are not homogeneous and differ in physical and chemical features (Val & Almeida-Val, 1995), making the selection of identical river replicates impossible. The rivers that were selected were similar in size and as many characteristics as possible while still being in the same geographic region; nevertheless they showed differences in habitat measurements, mainly pH and conductivity. The low pH and conductivity sites were those that also had higher fishing pressure, and there is abundant literature from temperate (Marsh-Matthews & Matthews, 2000) and tropical (Burcham, 1988; Galacatos *et al.*, 1996; Petry *et al.*, 2003) rivers showing the impact of habitat on fish populations. The strength of the habitat regression relationships, however, was not high for any of the fishery variables, explaining at most 13% of the variation seen, and there is no reason to expect that fishing pressure and habitat influences are mutually exclusive explanations for the differences found among locations.

Although these factors may have contributed to the lowered abundance, species diversity and biomass in the heavily fished Rio Nanay locations, it seems probable that some of the difference can be attributed to the original hypothesis of overfishing, due to the significant differences in fishery values among locations, and the lack of strong evidence for other possible explanations. The data from this study do not give a definitive explanation for the among-location differences, but they do provide important base-line information for comparison with future studies of freshwater aquarium trade fishes.

Another interesting finding from the results is that seine data showed no significant differences between the medium and low fishing pressure areas. This could indicate that a moderate amount of fishing is possible without negatively impacting aquarium fish populations. Management solutions for the trade could thus include the establishment of managed extractive reserve areas or the establishment of quotas for collectors from indigenous communities to promote local economic opportunities and the long-term sustainability of the fishery. Success has been evident in the recovery and sustainable use of food fisheries in the Mamiraua Sustainable Use Reserve in Brazil (Koziell & Inoue, 2004), and the data may indicate success in the protection of aquarium fish populations in Pacaya-Samiria National Reserve. Managed collection of freshwater aquarium fishes has been promoted recently in rapid biodiversity assessments of tropical aquatic habitats (AquaRap) (Machado-Allison *et al.*, 2003), and could be a preferred solution for managing the trade than the captive rearing suggested for the marine aquarium trade. While captive rearing may ameliorate pressure on wild fish populations, such activity should probably be concentrated close to export centres or even be transferred to other countries with lower labour costs. Captive rearing would thus probably have a negative impact on the economics of local people in more remote and pristine areas, and would remove incentives for conservation of fish habitat. Although this study examined the impact of the freshwater aquarium trade on wild fish populations and produced base-line data, more extensive research on the population ecology, life-history traits, habitat needs and trade statistics of Peruvian aquarium fishes will be needed to conclusively determine whether the freshwater aquarium trade can truly be sustainable.

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