Fisheries Management
and Ecology

Fisheries Management and Ecology, 2008, **15**, 93–98

Analysis of the trophy sport fishery for the speckled peacock bass in the Rio Negro River, Brazil

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Abstract The middle portion of the Rio Negro River in Brazil near the equator supports a popular recreational sport fishery for speckled peacock bass, *Cichla temensis* (Humboldt). The objective of this study was to determine the effect of fishing mortality on this population. Fish were collected from sport-fishing ($n = 72$) and commercial ($n = 103$) catches and otoliths were aged to estimate longevity, growth and natural mortality. Recreational anglers in this region seek to catch, then release, larger speckled peacock bass; and fish larger than 62 cm standard length (SL) (about 4.5 kg) served as a bench mark to assess the potential impact of subsistence and commercial harvest on the abundance of larger fish in the sport fishery. Time of opaque band formation on otoliths generally coincided with the dry season (November to April); these bands appeared to form once per year, but formation was highly variable. Speckled peacock bass grew to 62 cm SL on average in 6.4 years, but some fish obtained this size in 4–5 years. Maximum age was 9 years, but most fish were less than 7 years. Instantaneous annual natural mortality (M) estimated from maximum size, longevity and growth ranged from 0.19 to 0.44. Simulation modelling predicted that exploitation rates of fish >25 cm SL similar to the estimated natural mortality rates would reduce the abundance of fish >62 cm by 67–89% compared with no harvest. Even modest exploitation rates of 5% and 10% would result in approximately 30–50% reduction, respectively, of these larger fish. Abundance of large speckled peacock bass that sustains the sport fishery is susceptible to low rates of exploitation in this remote region of Brazil.

KEYWORDS: ageing, Brazil, growth, otoliths, simulation modelling, speckled peacock bass.

Introduction

A sport-fishing industry directed at cichlids has emerged in the Rio Negro River, Brazil, a tributary of the Amazon River (Fig. 1), during the past 15 years. At least eight fishing outfitters provide fishing services on the Rio Negro River upstream from the town of Barcelos, which attracts approximately 1400–1800 anglers to the region annually and contributes about US $5–6 million in expenditures (P. Marsteller, personal communication). The speckled peacock bass *Cichla temensis* (Humboldt), which can attain large sizes (12 kg), is one of three *Cichla* species sought by sport anglers in the Rio Negro River. Demographic data for this species in the middle Rio Negro River are essentially non-existent. Currently, there is an extensive catch-and-release sport fishery for these cichlid species. Commercial fishing also occurs in this region

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 doi: 10.1111/j.1365-2400.2007.00587.x

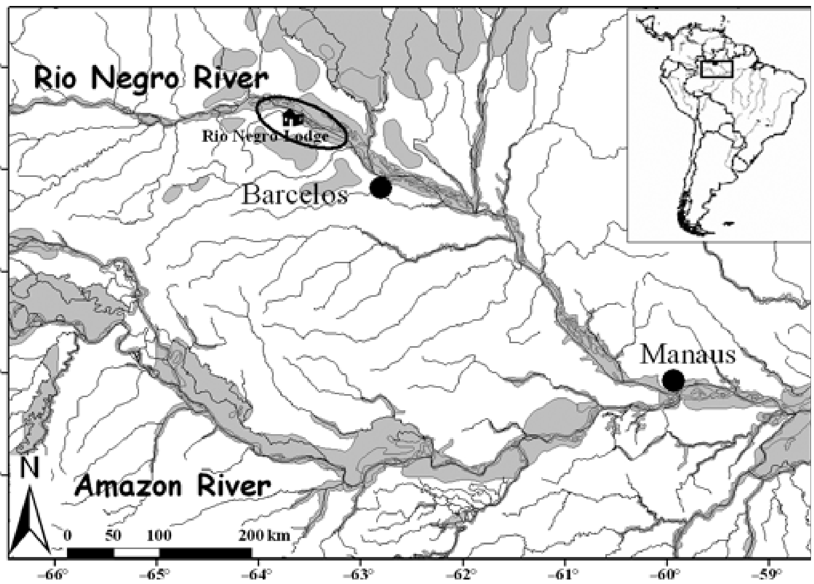

Figure 1. Location of the middle Rio Negro River, Barcelos, and the Rio Negro Lodge where speckled peacock bass were collected (circled area).

and sport-fishing outfitters have expressed concerns that this activity may negatively effect and compromise the quality of the sport fishery offered by these outfitters.

The ability to describe fish population dynamics needed to assess the impact of exploitation depends on accurate age data. Although obtaining accurate estimates of age from fish inhabiting the tropics has been considered difficult, Morales-Nin & Panfili (2005) reviewed published literature and reported that many authors had success in ageing fish from these regions using innovative processing techniques that have been developed over the last 10 years. Furthermore, incremental depositional zones (annuli) on otoliths from fish in the tropics were related to seasonal climatic conditions that caused annual variation in hydrologic cycles and not temperature (Morales-Nin & Panfili 2005). For *C. temensis*, *Cichla orinocensis* (Humboldt) and *Cichla intermedia* (Machado), deposition of opaque zones, or annuli, on the otolith occurred during the onset and period of low water conditions and appeared to coincide with spawning (Jepsen, Winemiller, Taphorn & Rodriguez Olarte 1999). In Venezuela, maximum age of speckled peacock bass estimated from otoliths was 9 years (Winemiller 2001), and some fish attained standard lengths (SL) >60 cm in less than 5 years (Jepsen *et al.* 1999). Although considered abundant, Winemiller (2001) and Hoeinghaus, Layman, Arrington & Winemiller (2003) speculated that over-exploitation and illegal netting threatened the sustainability of the *Cichla* sport fishery in Venezuela, similar to concerns in the middle Rio Negro River, Brazil. The objectives of this study were to estimate growth and longevity and assess the impact of exploitation on the abundance of large (>62 cm SL or 4.5 kg) speckled peacock bass over a range of estimated natural and fishing mortality rates in the middle Rio Negro River.

Materials and methods

Speckled peacock bass were collected from recreational (rod and reel) and commercial fishers (spearing) during December 2003 to January 2007 in the middle Rio Negro River (0°34′ S; 63°27′ W) near Barcelos in Amazonia, Brazil, approximately 500 km upstream from Manaus (Fig. 1). An attempt was made to collect fish that ranged in size from the smallest to largest fish that were caught by recreational and commercial fishers. Standard length was measured to the nearest cm, weight was recorded to the nearest 30 g, and sagittal otoliths were removed. A total of 1347 speckled peacock bass caught by angling between 2003 and 2006 were tagged with numbered Floy® T-bar anchor tags (Floy Tag Inc., Seattle, WA, USA) then released. A reward was offered for recaptured fish to estimate the proportion of fish harvested by subsistence and commercial anglers.

Otoliths were sectioned according to the procedures of Maceina (1988). Counts of annuli were made under a dissecting microscope (40× magnification) using a fibre optic light to illuminate the surface of the otolith.

Two independent readers enumerated annuli, and discrepancies between readers were resolved with an additional read or a concert read viewed on an image analysis system (Image Pro Software 2002; Media Cybernetics, Inc. Bethesda, MD, USA) that was used to create digital images of otoliths. Otolith radius was measured from the centre of the nucleus to the edge of the otolith along the sulcus groove, and distance to the last presumptive annulus was measured from the centre of the nucleus to the distal edge of the last opaque zone. The difference of the two measurements was the marginal increment. The median values of marginal increments were plotted for each month to assess whether an annual pattern of annulus formation occurred.

Growth was described using the von Bertalanffy (1938) growth equation:

$$L_t = L_\infty[1 - e^{-k(t-t_0)}]$$

where L_t is the predicted SL in cm at age t; L_∞ is the asymptotic length in cm, t is age in years and t_0 is the time in years when SL would theoretically be equal to zero. Mean length-at-age data and L_∞ constrained to 83 cm SL were used to compute the von Bertalanffy equation. The L_∞ of 83 cm is the length of the world record speckled peacock bass that was caught by an angler in this region in 1994 (http://www.peacock-bassfishing.com). This length was measured from the mounted fish by the authors and was similar to the largest fish collected by Winemiller (2001) in Venezuela (81 cm SL). The weight–length relation was described using linear regression of $\log_{10}$-transformed variables to predict the length of speckled peacock bass at 4.5 kg and the theoretical maximum weight of a speckled peacock bass based on L_∞.

Instantaneous natural mortality rates (M) were estimated from empirical and theoretical equations (see Table 1) presented by Hoenig (1983), Peterson & Wroblewski (1984), Chen & Watanabe (1989), Jensen (1996) and Quinn & Deriso (1999). These estimators have assumptions, but M was inversely related to maximum size attained and longevity and positively related to the growth coefficient K. The population response was modelled over the approximated minimum (M = 0.2) and maximum (M = 0.4) natural mortality rates estimated from these equations. For modelling, the minimum length in the fishery was 25 cm SL, which was the minimum length retained by commercial fishers in our data base. The number of fish entering the fishery at 25 cm ($N_{t\,=\,25\text{cm}}$) was set at 100 for each simulation and the number of fish (62 cm) entering the population ($N_{t\,=\,62\text{cm}}$) was computed from:

$$N_{t=62\text{cm}} = 100\,e^{-(M+F)}$$

where M is the instantaneous rate of natural mortality (0.20, 0.30 and 0.40); and F is the instantaneous rate of fishing mortality that varied from 0 to a maximum of 0.40.

Table 1. Sources, equations and estimates of natural mortality M based on population demographics of speckled peacock bass from the middle Rio Negro River, Brazil

Source	Equation to estimate M	M
Quinn & Deriso (1999)	$-\log_e(\text{Ps})/\text{Max}_{\text{age}}$	0.33
Hoenig (1983)	$1.46 - 1.01\log_e(\text{Max}_{\text{age}})$	0.47
Jensen (1996)	$1.50K$	0.27
Peterson & Wroblewski (1984)	$1.92(\text{Max}_{\text{wt}}^{0.25})$	0.19
Chen & Watanabe (1989)	$(1/t_f - t_i)\log_e(e^{Kt_f} - e^{Kt_0})/(e^{Kt_i} - e^{Kt_0})$	0.28

Definitions of variables used in these equations are found below or in Table 2. Ps, proportion of fish surviving to the maximum age which was set at 0.05; Max_{wt}, the maximum weight of fish computed from the weight:length regression in Table 2 for L_∞; t_f, final age which was assumed as maximum age; t_i, initial age which was assumed as 1 year.

The Fishery Analysis and Simulation Tools software (Slipke & Maceina 2007) using the Jones modification of the Beverton–Holt equilibrium yield equation (see Quinn & Deriso 1999) was used to model the population to evaluate the impact of fishing mortality on the abundance of 62 cm SL fish over a range of estimated natural mortality rates. For the lower, intermediate and upper values of the estimated natural mortality rates, the number of fish obtaining 62 cm without fishing mortality was predicted. Then, instantaneous fishing mortality (F) was increased in the simulation model to a conservative Biological Reference Point for moderate harvest (the point at which fishing mortality equalled natural mortality; suggested by Quinn & Deriso 1999), and the number of 62 cm SL fish remaining in the population after harvest was predicted. The number of 62 cm SL fish entering the fishery was plotted against exploitation for each level of natural mortality and exploitation (u) where M and F occur concomitantly was computed from:

$$u = (F/Z)(1 - S)$$

where

$$Z = F + M \text{ and } S = e^{-Z}.$$

Results

A total of 72 and 103 speckled peacock bass were collected by angling and commercial fishers respectively. Angled fish averaged 42 cm SL (range 19–69 cm SL) and commercially caught fish averaged 53 cm SL (range 25–77 cm SL). Ages were obtained from 170 otoliths, and measurements for marginal increment analysis were preformed on 159 otoliths; thus seven otoliths had no visible opaque band (presumed age-0 fish) and four otoliths could be not be read because of poor visibility. Estimates of precision for exact age agreement were low (43%) for speckled peacock bass from the Rio Negro River; however, agreement of ages within 1 year between the two readers was higher (81%).

With the exception of April and December, median values for marginal increments tended to be lower from November to May than in June to October (Fig. 2). Fish were not collected in March. Based on minimum and maximum measurements for marginal increments, time of opaque band formation was variable, but generally appeared to form in most fish from November to May and was assumed to represent annuli on the otoliths. Exact age agreement between the two readers was 43%, but age agreement within 1 year was 81%.

Age ranged from 0 to 9 years and speckled peacock bass attained 25 cm (smallest size harvested by commercial anglers) in less than 1 year; fish grew to 62 cm on average in 6.4 years, but some fish attained this length in 4–5 years (Fig. 3). Almost all fish 19–25 cm were age-0, but one age-1 and one age-2 fish were collected in this size range. The largest individual (77 cm) was only 6 years old, and growth was highly variable among all sizes of fish collected.

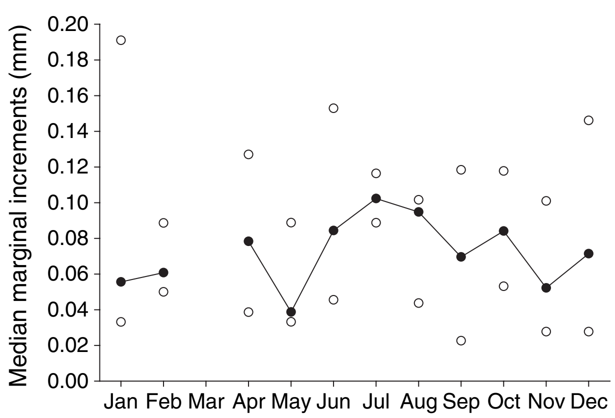

Figure 2. Temporal trend in median marginal increment for speckled peacock bass. Minimum and maximum values are also shown.

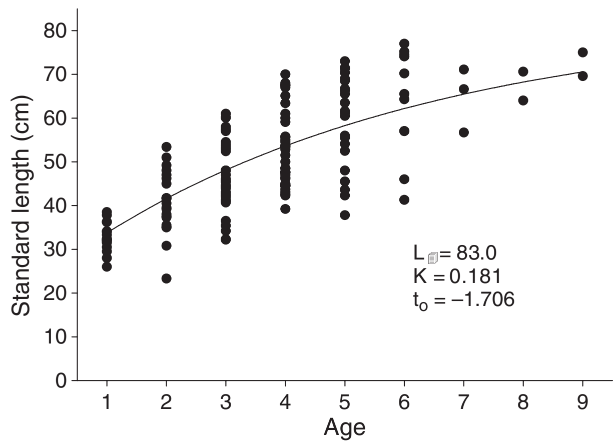

Figure 3. von Bertalanffy growth curve and associated equation coefficients for speckled peacock bass. Line represents predicted regression values from mean length-at-age data and dots represent observed lengths-at-age.

Recapture data from Floy-tagged fish indicated that some harvest occurred in the study region upstream from Barcelos for speckled peacock bass. A total of 49 tagged fish were recaptured (3.6% recapture rate); nine of these were returned from commercial fishers and eight were returned from subsistence fishers. All other recaptures were from sport fishing, and these fish were released. Exploitation was not estimated because tag loss and angler non-reporting were not assessed.

Among the five natural mortality equations, M ranged from 0.19 to 0.47 (Table 1). These estimates closely coincided with the M values of 0.2, 0.3 and 0.4 used to predict the abundance of 62 cm SL speckled peacock bass at various levels of fishing mortality.

Simulation modelling (parameters listed in Table 2) predicted that when fishing mortality (F) was the same as natural mortality (M), a 67–89% reduction in the number of 62 cm SL fish entering the population would occur over the three rates of M (Fig. 4). Even low exploitation rates of only 5% and 10% would cause about a 27–29% and 48–51% decline in the numbers of 62 cm SL fish entering the population, respectively, over the range of natural mortality rates that were modelled (Fig. 4).

Discussion

The time of annulus formation appeared variable, but speckled peacock bass appeared to deposit annuli during the dry season (November to April) in the middle Rio Negro River, with peak annulus formation

Table 2. Parameters used to model the speckled peacock bass population in the Rio Negro River, Brazil

Parameter	Value
von Bertalanffy growth coefficients	L_∞ = 83 cm SL
	K = 0.181
	t_0 = −1.706
Maximum age (Max_{age})	9.5
Natural mortality (*M*)	0.2–0.4
Fishing mortality (*F*)	0–0.40
Exploitation (*u*)	0–0.36
Log_{10} weight:log_{10} length coefficients	Intercept = −4.595
	Slope = 2.954
Minimum length (SL)	25 cm

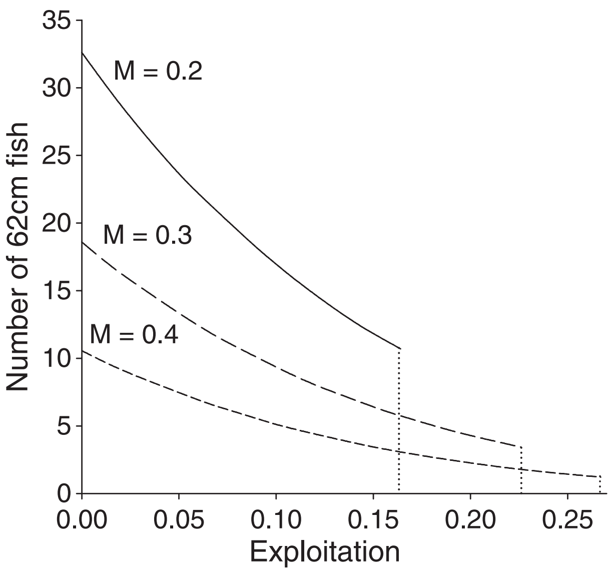

Figure 4. Predicted number of speckled peacock bass reaching 62 cm SL at varying levels of exploitation at three different rates of natural mortality (*M*). Where the dotted lines meet the *x*-axis is where fishing mortality (*F*) equals natural mortality (*M*) for each level of *M*.

occurring in May (onset of the wet season). Jepsen *et al.* (1999) found a similar temporal pattern of annulus formation for speckled peacock bass in the Psimoni and Siapa rivers, Venezuela, but found lower marginal increments (expressed as a percentage of otolith radius) occurred from November to March than observed for speckled peacock bass from the Rio Negro River. The gonadosomatic index (gonad weight/body weight) for female fish collected from the middle Rio Negro River was higher from November to April than from May to October (M. Thomé-Souza, unpublished data) and suggested that spawning took place during this time period. Jepsen *et al.* (1999) speculated otolith annulus formation of peacock bass species was associated with spawning, reduced feeding activity and a depletion of peritoneal fat reserves and body condition during the dry season. Jepsen *et al.* (1999) noted that interpretation of otolith annuli of some cichlids was difficult in a Venezuelan reservoir that fluctuated about 10 m each year, which may have affected spawning periodicity and food resources. Water levels typically rise about 5-6 m each year during the wet season on the middle Rio Negro River; but water level fluctuations also occur during the dry season, which may have influenced spawning periodicity and feeding of speckled peacock bass and possibly affected the time of annulus deposition.

Estimates of growth and longevity of speckled peacock bass in the Rio Negro River were similar to previously reported values in Venezuela (Jepsen *et al.*1999). Jepsen *et al.* (1999) reported L_∞, K and t_0 as 84.7 cm SL, 0.167 and −2.3, respectively, for speckled peacock bass in Venezuela; these coefficients were nearly identical to those computed for fish collected from the Rio Negro River (see Table 1). The maximum age in this study was 9 years, and some fish reached 62 cm SL in 4–5 years. Growth of speckled peacock bass in Venezuela (Jepsen *et al.* 1999) was similar to fish collected from the Rio Negro River, and maximum age was also 9 years (Winemiller 2001). Variation in size-at-age of fish collected from the Rio Negro River could be because of growth differences between sexes (cf. Jepsen *et al.* 1999), but this information was not collected from fish in the Rio Negro River. In addition, fish were collected nearly year round from the Rio Negro River and length would be expected to vary within a single age group. Age data are regularly used to assess fish population dynamics and are an essential component of age-structured population models that assist in fishery management. For this speckled peacock bass fishery, further investigations that validate ages accurately are warranted.

Using a Biological Reference Point of fishing mortality equal to natural mortality (Quinn & Deriso 1999), the relative abundance of fish ≥62 cm SL in this population can be reduced at low-to-moderate levels of exploitation. Exploitation rates are not known, but 28 of the 103 commercially caught fish that were collected for aging were ≥62 cm SL. Thus, larger fish are being exploited for market sale. However, fish as small as 25 cm were captured by commercial fishers, and the predicted abundance of fish ≥62 cm SL was vulnerable to even modest harvest (5–10%) throughout the range of natural mortality rates modelled at sizes greater than 25 cm.

Based on recapture locations of tagged fish, speckled peacock bass have moved up to 40 km yr^{-1} within the middle Rio Negro River basin (M. Thomé-Souza, unpublished data). Hoeinghaus *et al.* (2003) found speckled peacock bass moved up to 21 km in the Cinarucco River, Venezuela. Thus, the fishery in the middle Rio Negro River is not localised, and management of this species should consider this movement behaviour. The natural mortality equations used to estimate M in this study assumed populations were closed, which, based on these movement data and the length of the Rio Negro River, was a reasonable assumption.

To help manage this fishery and address conflicts between catch-and-release sport-fishing and commercial and subsistence harvest, additional data are needed including accurate estimates of exploitation. Winemiller (2001) and Hoeinghaus *et al.* (2003) speculated commercial harvest of cichlids could negatively impact the sport fisheries that currently exist in Venezuela. Analysis of data collected from the middle Rio Negro River in Brazil showed that even exploitation rates of less than 10% would significantly reduce the abundance of larger speckled peacock bass and negatively affect the trophy sport fishery.

Acknowledgments

Financial support of this study was provided by Fundação de Amparo a Pesquisas do Estado do Amazonas (FAPEAM) – Amazonas Verde – Edital Temático 008/2003. Fish were collected under Research Permit Numbers 2005.000201/04-07 and 2005.003143/03-20. Travel and field support to M. Holley and M. Maceina were graciously provided by Amazon Tours Inc. (P. Marsteller, President), the Rio Negro Foundation which purchased tags and equipment, and the International Center for Aquaculture and Aquatic Environments, Auburn University. Álvaro Carvalho, Carla Sardelli, Anderson Garcia and Adriano Rodrigues provided field support and collected data. Drs S. Sammons, K. Winemiller and two anonymous reviewers provided comments to improve this paper.

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