J. Appl. Ichthyol. 25 (2009), 294–298

ISSN 0175–8659

Received: June 26, 2007
Accepted: February 22, 2008
doi: 10.1111/j.1439-0426.2008.01122.x

Landscape variables affecting fishery yield in lake systems of the Central Amazon region, Brazil

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Summary

According to fisheries data, lakes are important systems for fish production in the Amazon basin. However, there is no information about the relationship between landscape variables and fishing yield that allows foresight into potential resource exploitation in this environment. The present study aims to evaluate this relationship with the hypothesis: lakes of different shapes give the same fishery yield in the Amazon, after considering the effects of lake size, distance to the river, fishing effort, fuel and ice used. Fishery data from 1994 to 1996 were analyzed with regard to 3228 trips on 50 lakes of the main white water tributaries of the Amazon basin. Analysis of covariance was applied to test this hypothesis. With variables such as fishing grounds access, fishing effort and lake shape the model explained a significant 72% of variabilities in the fisheries yield. Fishing yields among lake systems were different, thus the null hypothesis was rejected ($P < 0.05$). Results indicate that dendritic lakes far distant from the main river have greater productivity than floodplain lakes because there are more habitats of fish refuge for reproduction and feed available to the fish; there are also more limitations to access by predators.

Introduction

A major component for biotic productivity sustaining many aquatic resources in the Amazon basin is associated with the floodplain environment: white water flooded areas regionally known as 'várzea'. Lakes, flooded forests and other aquatic environments in the central Amazon permanently or temporary cover an estimated area of 400 000 to 500 000 km^2 (Junk et al., 1989; Junk, 1993; Goulding, 1996), equivalent to 17% of the total area (Hess et al., 2003) containing around 6500 to 8500 lakes (Melack, 1984; Sieppel et al., 1992). These aquatic environments are very diverse, where the lake systems are an important part of a mosaic of elements that compose the 'várzea' (Forsberg et al., 1988, 1993; Junk, 1997). At the edge of the 'várzea' and embedded in the non-floodable upland is the 'terra firme', where there are dendritic lakes with steep banks called ria lakes (Irion et al., 1997). The sediment-rich white water rivers increase productivity in the floodplains, generating considerable production and recruitment potential for the fishery and other human activities (Junk, 1993, 1997). The effect in the non-floodable 'terra firme' lakes system is less well known, although systems of this type seem to be more dependent on the forest input (Henderson and Crampton, 1997).

From the 1950s onward many investigators have used physical, chemical, and biological indices, or a combination thereof, to estimate the potential biological productivity (Moyle, 1956; Northcote and Larkin, 1956; Rawson, 1957, 1960). In particular the paper by Ryder (1965) was an important milestone relating fishery yield to environmental variables while generating the morphoedaphic index as a rule of thumb for classifying productivity.

In the tropics, some authors tested fishery and environmental variables, e.g. Melack (1976) with relationships of fish yields and primary production; Petrere (1983) relating yield to river morphology and fishing effort; Welcomme (1990) relating yield to river basin area, floodplain area and length of the river; and Petrere et al. (1998) modeling fishery yields of inland waters in Africa and the Central Amazon with the variables of discharge rate, basin area and length of the rivers. However, the effects of variables associated with lake morphology were not considered, although the diversity of lake types exploited by the regional fishery fleet is large enough to give an appropriate basis for testing its effect on the fishery yield.

The identification of lake morphometric variables affecting lacustrine fishery yields is possible and may be important to foresee fish landings and provide viable indicators of the problems of and reasons for supporting fish production in the region. To test this argument, we worked with the null hypothesis that Amazonian lakes of different shapes give the same fishery yield, and considered the effects of the lake size, distance to the river, fishing effort, fuel and amount of ice used.

Materials and methods

This study used information on 50 lakes located in the main white water tributaries of the Amazon basin: the Madeira, Purus, Solimões and Juruá rivers (Fig. 1). For the period 1994–1996, 5774 records of the commercial fleet from Manaus in Amazon State were obtained; 3228 of these records were applied to identifiable lakes. These records (see Appendix) included information on: the fishing grounds and locale, main tributary and local lake name; the fishery, with the annual multispecies fish yield (tonnes) and fishing effort in number of fishermen / days spent fishing (Petrere, 1978); the amount of diesel oil used during the trip in liters and ice spent in tonnes were complementary variables that might have influenced the fishery effort (Hilborn and Walters, 1992). The catch per unit effort (CPUE) is traditionally defined in the region as weight of fish caught / (number of fishermen / days fishing).

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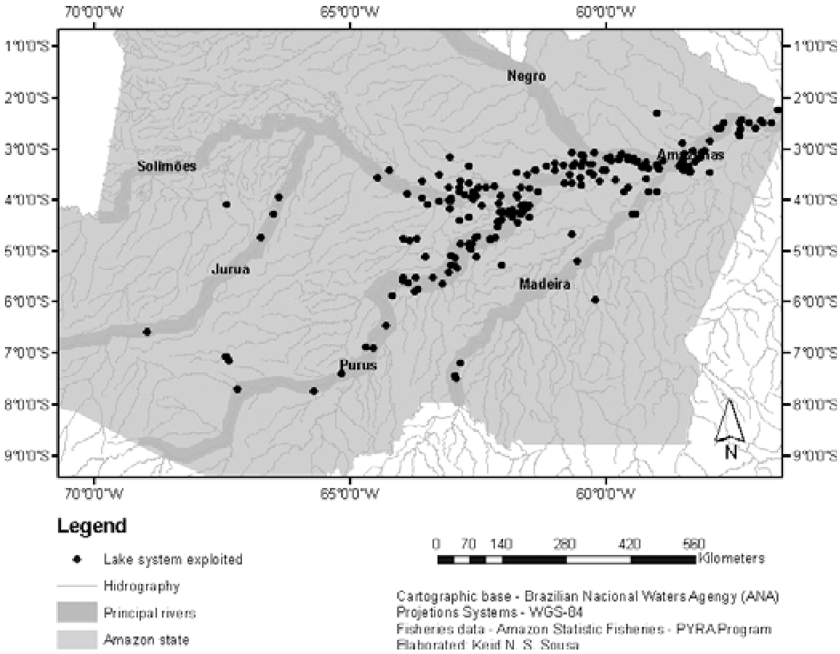

Fig. 1. Map with principal rivers of Amazon basin. Dots = lake positions included in fish yield analysis

Landscape variables were used for lake categorization: type or shape of the lake, consideration of its location ('várzea' or 'terra firme'), and morphometric variables: total lake area (hectare) and fishing grounds access (kilometer distance between the lake and the nearest river). The mean river level was not different in the years analyzed (Table 1). Independence of the catch samples was assumed because large distances between the lakes and competition among fishermen reduce any time influences between catches. To estimate morphometric variable values we used the cartographic basics of the RADAM-Brazil-Project and the mosaic of the L-band synthetic aperture radar (JARS ⁄ NASDA ⁄ MITI) imagery of the Amazon region.

The hypothesis was tested using the analysis of covariance after evaluation of assumptions. Absence of multicollinearity, the linear correlation amongst two or more explanatory variables in a model, was assumed after examining the determination correlation matrix for large coefficients (none superior to 0.5 was found). The dependent variable was the fish yield normalized by a squared root transformation. Lake environment co-variables of the model were the lake surface area (ha) and fishing grounds access (km). Fishing co-variables were the squared root of the fishing effort, logarithm of the diesel oil and the ice used for the fishing trip. The covariance model factor was the 'lake shape' with five levels. Open interviews with fishermen were conducted to learn the dynamics of the fishery in lake types of the region.

Results

The lake systems identified in Amazon white water tributaries were classified according to their landscapes into three categories. The two extreme categories were: lake systems located in floodplain areas ('várzea' lakes), and lake systems located in the upland areas ('terra firme' lakes); the intermediate category of lakes had similar areas of 'terra firme' and 'várzea' environments. The first landscape category has two types according to the shape: oval to rounded and horseshoe; both are frequent in the Amazon and Madeira rivers, and with the horseshoe shape prevalent in the Purus River. Within the second landscape category we identified two types: stretched dendritic and branched dendritic, characteristic of the Medium Amazon.

Data indicate that the analyzed 'terra firme' lakes were larger and their size more variable than 'várzea' lakes, although irregular ⁄ composite lakes were the largest in size in the analysis (Fig. 2). The distance to the river is also greater for 'terra firme' lakes, particularly for stretched dendritic lakes; this coincides with the information from fishermen about their difficulties in gaining entry to these types of lake.

On the one hand, the CPUE of stretched dendritic and branched dendritic 'terra firme' lakes was around 30% superior to the horseshoe and rounded 'várzea' lakes (Table 2; Fig. 3). This pattern is particularly interesting after verifying that the

Table 1
1994–1996 mean river level variations with low-high limits

Year	High	Low	Mean
1994	2.90	1.95	2.53
1995	2.70	1.57	2.21
1996	2.85	1.92	2.42

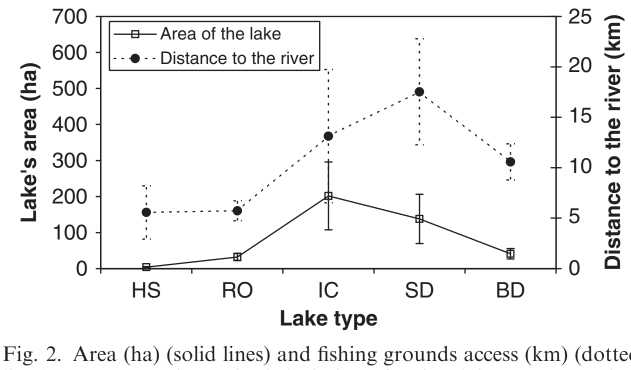

Fig. 2. Area (ha) (solid lines) and fishing grounds access (km) (dotted lines) averages and standard deviations for five lake types. Vertical lines indicate standard error. HS, horseshoe; RO, rounded ⁄ oval; IC, irregular ⁄ composite; SD, stretched dendritic; BD, branched dendritic

Table 2
Mean and standard deviation of area (ha), fishing grounds access (km), effort (number of fishermen ⁄ days fishing), yield (tonnes) and catch per unit effort (CPUE) (kg ⁄ fishermen 3 × day fishing) to different lake shapes, 1994–1996. Number of lakes evaluated (NL); number of fishing trips recorded from lakes (NT)

Environment	Shape	NL	Mean area	Fishing grounds access	Effort	Yield	CPUE	NT
'Várzea'	Horseshoe	18	4.04 ± 1.39	5.57 ± 2.64	390.21 ± 144.54	16.41 ± 5.14	42.52 ± 2.58	55
	Rounded ⁄ oval	16	32.24 ± 41.64	17.53 ± 20.39	193.22 ± 69.86	7.91 ± 4.44	38.15 ± 14.57	1.439
Mixed	Irregular ⁄ composite	12	201.61 ± 94.14	10.58 ± 5.95	190.56 ± 144.54	7.49 ± 0.69	42.31 ± 14.31	161
'Terra firme'	Stretched dendritic	2	137.91 ± 263.84	5.73 ± 4.06	226.84 ± 50.73	12.73 ± 5.15	56.56 ± 21.07	522
	Branched dendritic	2	41.06 ± 48.15	13.13 ± 6.60	165.33 ± 53.97	9.02 ± 2.98	58.05 ± 17.24	1.051

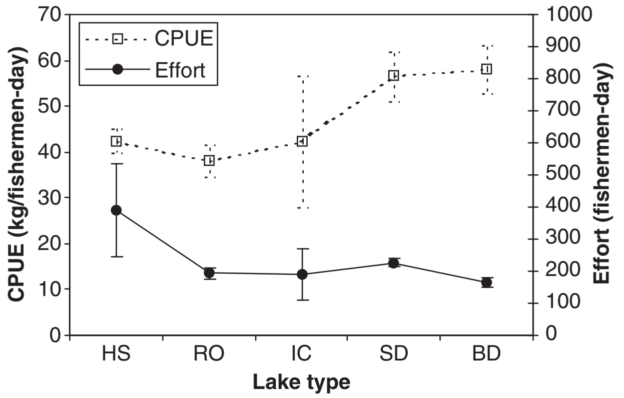

Fig. 3. Dispersion diagram for capture (tonnes) and effort (number of fishermen ⁄ days fishing) for different lake types. HS, horseshoe; RO, rounded ⁄ oval; IC, irregular ⁄ composite; SD, stretched dendritic; BD, branched dendritic

effort for horseshoe lakes was higher and very variable. On the other hand, the irregular composite lakes CPUE was very diverse, differing from the other lakes.

The variables in fishing grounds access, fishing effort and lake shape explained a significant 72% of the fishery yield variability. The 'lake type' factors were significantly different ($P < 0.05$) (Table 3).

The test indicated a negative relationship between the fish yield and access to the fishing grounds. The stretched dendritic (SD) and branched dendritic (BD) lake fish yields were significantly superior to those of the horseshoe (HS) and rounded (RO) lakes, thus we rejected the null hypothesis ($P < 0.05$). Other fishing co-variables were not significant in explaining the variability of the fishing yield in the different lake systems.

Table 3
ANCOVA analysis results to test relationships between Amazon fish yield with lake variables (fishing grounds access and lake shape) and fishery variables (motor oil and ice used in fisheries and fishing effort) ($n = 50$, $r = 0.85$, $r^2 = 0.72$)

Source	SS	d.f.	MS	*F*	Coefficient	SE	*t*
Fishing grounds access	0.99	1	0.99	4.24*	−0.64	0.31	−2.06
Oil	0.13	1	0.13	0.54	0.48	0.65	0.73
Ice	0.02	1	0.02	0.07	0.23	0.89	0.26
Effort	6.90	1	6.90	29.53*	0.19	0.03	5.43
Area	0.02	1	0.02	0.09	0.04	0.14	0.29
Shape	3.71	4	3.71	3.98*	–	–	–
Error	9.34	40	0.23	–	–	–	–

*$P < 0.05$.

Discussion

The landscape is a functional level of organization within the system, which focused on space patterns and related processes considering space interactions and seasonal interactions (Jongman et al., 1995). In this sense, our results showed that environmental factors mainly determine differences between 'várzea' and 'terra firme' lakes and that the distance between the system of lake and the river can influence the fish yield. The dendritic lakes located in 'terra firme' areas in the Amazon basin were more productive for fishermen than were the round or oval 'várzea' lakes.

The effect of the lake shape on fishery yields shows that lakes with more complex space mosaics ('terra firme' lakes) give better fishing results. This complex shape increases the perimeter of the aquatic-terrestrial zone, increasing exogenous input to feed lake fauna, but the higher CPUE may be related to accessibility problems. River distances are greater to 'terra firme' lakes, which are environmentally more fragmented, and in turn are harder to fish. Besides the greater CPUE, this situation reduces access to dendritic lakes by some fishermen, which may facilitate conservation of the fish resources and be a factor in maintaining high levels of fishery productivity.

The results also agree with the hypothesis that environmental heterogeneity can determine differences in productivity of the system as a whole (MacArthur and Pianka, 1966). This is suggested by the significant effect of shape over the fishery yield in the function estimated by the general lineal model, similar in approach to Schneider and Haedrich (1989) who reanalyzed Ryder's morphometric index. Goulding (1996) had also already indicated the productivity potential of the seasonally flooded land, focusing on the flooded forest. In the larger areas of 'terra firme' lakes, there is a large zone of contact with the neighboring forests and aquatic environment, combining a greater variety of energy sources for the food chain with their broad environmental complexity. For this reason, the stretched dendritic, branched dendritic and irregular-composite lakes might have greater CPUE than the oval-to-rounded and horseshoe-shaped lakes.

On the other hand, there is an intensive exploitation of fish resources in lakes closer to the river, particularly horseshoe and irregular ⁄ composite lakes, increasing the variability of the effort and CPUE in these categories. These types of systems can be addressed as more vulnerable to fishery activities and should be closely monitored in management activities. 'Várzea' regions are also more attractive and vulnerable to agriculture and cattle activities, as the soil is annually fertilized by nutrients from white water rivers such as the Amazon, Purus and Madeira (Junk, 2000). Landscape modifications caused by these activities, particularly in the riparian vegetation of the wetlands, may contribute to destruction of the spawning and nursery fish habitats, in turn affecting fish diversity and fishery yield (Roth et al., 1996; Batista et al., 2000; Angelini et al., 2006), although Granado-Lorencio et al. (2005) did not find such relationships in 36 floodplain lakes of the region.

The distance of lake-to-river showed an inverse pattern as to fishery yield: the higher the yield, the larger the distance of the lake to the river, confirming that lake accessibility affects fishing intensity (Ryder, 1965). The farther the lakes are from the river, the more difficult 'the success of fishing' becomes due to the horizontal physiographic complexity of the system, such as numerous small channel creeks and temporary bodies of water, as much as by various forest types (Junk, 1997). Biological connectivity was also an important factor for fish diversity in lakes of the Central Amazon (Granado-Lorencio et al., 2005). Environments far from the main river should be considered as important for fishes because of their numerous habitats for refuge, reproduction and feeding (Araújo-Lima et al., 1995). In this context, freshwater fish diversity, recruitment and production depends directly upon riparian ecotones and, consequently, upon the lateral complex habitats (Zalewski et al., 2001), which need to be identified and considered as special units for management plans.

The present study also confirms that effort is an important component for fishery evaluation in these lakes, confirming the importance of effort as a tool in issues concerning management. However, managers must also consider the spatial position of the lake to the river as well as the lake type when designing management plans. Limitations on fish catch caused by variables in fishery operations, such as the amount of ice and oil used in the fishing trip, were tested, however these covariables did not significantly affect the catch in this study.

The large spatial scale of this study may also have influenced present research conclusions since competition and other local effects have usually been observed in small-scale studies (Jackson et al., 2001). As here, abiotic factors have commonly been most important in large-scale studies, thus local effects in particular must be evaluated for management purposes.

These findings confirm the need for a different type of management for each ecosystem according to its particular properties, which consider the various environmental scopes involved. This may be a new direction of development in fishery policies, particularly with regard to the development of co-management strategies using fishing agreements that permit different rules for each aquatic and floodplain environment.

Acknowledgements

CNPq (National Council of Research), SUDAM (Agency for the Development of the Amazon) and FNMA (National Fund of Environment) supported this study. We are grateful to Miguel Petrere and Peter Bayley for their suggestions and to technicians F. C. Silva and I. L. Santos for their help in processing the data. PYRÁ (Integrated Program of the Aquatic Resources and Floodplains) of the Federal University of Amazonas and INPA (National Institute of Research of the Amazon) provided resources and information to make this paper possible.

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Appendix

Basic metadata of Amazonian lakes used in research with mean values per trip. Lake shapes identified: HO, horseshoe; RO, rounded ⁄ oval; IC, irregular ⁄ composite; SD, stretched dendritic; BD, branched dendritic.

Lake	Main tributary	Shape	Yield (tonnes)	Number of fishermen	Days fishing	Effort (nf*df)	Área (km^2)	Distance to river (km)	Diesel oil	Ice
3 Casas	Madeira	HO	7.21	9.89	23.78	235.14	49.93	5.75	366.67	6.22
Aiapuá	Purus	BD	7.97	9.57	25.87	247.59	268.18	8.46	559.3	10.02
Amatari	High Amazon	HO	10.53	9.09	25.95	235.99	0.31	0.67	389.53	9.26
Anamã	Low Solimões	IC	11.55	8.54	23.79	203.03	140.39	17.65	379.29	8.91
Andirá	Juruá	SD	20.04	12.43	39.62	492.41	3.05	7.43	659.52	16.19
Anori	Low Solimões	IC	7.05	8.94	18.38	164.37	31	6.35	390.11	7.67
Apui	Madeira	RO	24.85	9	25	225	0.32	1.7	600	5
Arari	High Amazon	HO	10.93	8.93	25.53	228.1	11.09	4.4	300	6.16
Arauá	Madeira	IC	11.4	8.86	20	177.14	1.2	0.72	421.43	7.1
Aruanã	Middle Solimões	RO	20.01	11	21	231	0.48	1.35	200	3
Badajós	Low Solimões	RO	7.35	9.02	18.13	163.58	75.64	74.9	630.21	10.9
Beruri	Purus	IC	8.29	9.74	17.33	168.87	21.36	9.1	537.17	11.2
Caiambé	Middle Solimões	RO	11.17	10.38	22	228.46	33.63	12.46	446.15	7.12
Caldeirão	Low Solimões	RO	5.12	8.56	18.78	160.65	1.76	1.84	272.22	3.72
Câmara	Middle Solimões	HO	13.92	10.78	23.78	256.27	6.62	2.8	472.22	7.44
Cassiana	Purus	SD	12.77	10.67	27	288	5.02	3.7	355.56	8.17
Castanho	High Amazon	IC	10.34	8	20	160	13.9	17.4	250	5
Coari	Middle Solimões	RO	12.12	12.29	14.29	175.51	961.99	30.79	771.43	15.29
Copeá	Middle Solimões	RO	9.91	10.27	25.15	258.4	1.08	12.06	551.23	10.08
Ena	Low Solimões	HO	2.52	8	15	120	1.69	1.94	200	4
Flexal	Madeira	RO	10.09	10.57	23.43	247.67	0.45	1.8	500	6.33
Grande	Low Solimões	HO	1.01	5.5	14.75	81.13	56.75	7.81	365	4.25
Ipiranga	Purus	IC	13.1	9.46	21.54	203.79	2.91	2.77	500	6.23
Itaboca	Purus	RO	14.46	11.22	23.44	263.1	18.21	6.02	555.56	8.89
Jacaré	Low Solimões	IC	4.58	7.33	11.67	85.56	13.9	7.07	266.67	3.93
Jacarezinho	High Amazon	HO	4.85	7	21.17	148.17	5.03	2.44	441.67	5.17
Janauacá	Low Solimões	BD	7	8.25	16.18	133.53	135.04	17.8	394.52	9.02
Jari	Purus	RO	10.28	10.41	23.61	245.76	355.4	25	1200	15
Jurupari	High Amazon	HO	8.22	8.06	20	161.11	17.16	2.6	319.44	4.61
Jutica	Middle Solimões	HO	14.07	10	22	220	4.05	0.99	600	6
Lima	Middle Solimões	RO	15.03	9.27	21.36	198.1	0.15	1.17	495.45	6.82
Mamiá	Middle Solimões	RO	9.97	10.05	21.77	218.7	255	22.02	507.54	9.3
Mamori	Low Solimões	RO	8.35	9.48	14.91	141.35	21.2	34.6	539.13	9.91
Manaquiri	Low Solimões	IC	11.14	8.08	20.14	162.82	135.59	17.5	297.55	6.14
Matamata	Madeira	HO	11.99	9.36	28.45	266.44	24.83	5.09	800	10
Miuá	Middle Solimões	IC	3.75	7	5.33	37.33	64.67	11.18	766.67	8.17
Murutinga	High Amazon	IC	10.28	8.87	20.78	184.33	26.79	15.1	290	6.67
Pesqueiro	Low Solimões	IC	6.38	8	26	208	17.25	0.9	200	4
Piorini	Low Solimões	RO	12.08	10.55	23.7	250.04	473.3	43.08	485	8.1
Piranha	High Amazon	HO	1.81	6.74	11.16	75.2	27.54	15.7	246.32	4.54
Piranha	Low Solimões	HO	3.19	8.5	24	204	26.45	14.6	300	4.5
Piranha	Purus	HO	8.96	12.4	21.8	270.32	2.2	6.32	540	7.6
Pupunhas	Madeira	RO	19.88	11.45	24.73	283.24	2.49	3.4	500	7.82
Pupunhas	Purus	RO	12.93	10.7	31.67	338.83	5.38	8.3	488.89	11.6
Rei	High Amazon	HO	9.86	8.03	24.71	198.47	128.33	10.4	276.94	8.9
Sampaio	High Amazon	HO	6.6	6	26	156	98.31	6.3	300	10
Sampaio	Madeira	HO	10.97	10.13	28.8	291.6	108.31	5.97	409.38	12.93
Surara	Purus	IC	10.43	9.64	23.74	228.75	14.16	7.02	462.07	7.15
Tambaqui	Purus	HO	13.61	10.42	24	250	0.63	4.24	554.17	7.92
Tucunaré	High Amazon	HO	2.09	5	16	80	2.11	6.6	200	3