Reduced dry season fish biomass and depleted carnivorous fish assemblages in unprotected tropical oxbow lakes

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Supplementary material

The following are the supplementary data related to this article.

Table S1. Locations and environmental metrics, of Oxbow lakes sampled for fish. Sampling was performed in the Madre de Dios province, Peru during 2018-2019.

Lake name	Area	Latitude (S)	Longitude (W)	Area (ha)	Elevation (m)	Distance from river (km)	Proportion mined bank
Aguajal	Protected	12°27'56"	70°39'55"	47.4	277	1.52	0
Blanco	Protected	12°24'16"	70°43'17"	81.7	281	1.4	0
Brasco	Protected	12°10'03"	71°02'19"	17.4	302	1.11	0
Camungo	Protected	12°25'52"	70°40'42"	33.5	279	1.6	0
Cashu	Protected	11°53'04"	71°24'36"	21.5	410	0.83	0
Garza	Protected	12°08'31"	71°05'40"	10.3	416	0.85	0
Juarez	Protected	12°02'49"	71°11'19"	28.4	310	0.93	0
Lagarto	Protected	12°10'03"	71°02'19"	24.8	373	0.87	0
Maisal	Protected	11°51'07"	71°28'22"	50.1	391	1.22	0
Nueva22	Protected	12°22'58"	70°43'57"	17.3	281	0.92	0
Otorongo	Protected	12°02'49"	71°11'19"	60.7	483	0.68	0
Salvador	Protected	11°59'46"	71°13'14"	108.1	393	0.92	0
Huitoto	Mined	12°37'30"	69°58'55"	199.8	232	1.54	0.37
Bajo04	Mined	12°37'03"	69°32'38"	71.0	206	1.74	0.51
Bajo06	Mined	12°43'06"	69°47'48"	115.3	228	1.89	0.33
Bajo07	Mined	12°41'54"	69°49'43"	51.7	236	2.76	0.12
Bajo09	Mined	12°36'14"	70°11'31"	128.8	233	1.78	0.15
Bajo10	Mined	12°38'43"	69°57'25"	69.7	235	0.99	0.07
Bajo11	Mined	12°38'03"	70°01'43"	86.3	247	1.64	0.06
Bajo11a	Mined	12°34'46"	70°05'00"	8.8	239	0.94	0.18
Bajo12	Mined	12°35'59"	70°03'59"	71.8	240	1.18	0.16
Bajo16	Mined	12°36'14"	70°11'31"	49.4	249	1.89	0.06

Table S2. Locations, catch total and species richness estimates of Oxbow lakes sampled for fish. Sampling was performed in the Madre de Dios province, Peru during 2018-2019.

Lake name	Area	Sampling month	total catch	Catch/ effort	Biomass (kg)	S_{all}[c1]	S_{jack}[c2]	Sampling completeness[3]
Aguajal	Protected	May	42	7.0	12.7	18	24.5	0.893
Blanco	Protected	May	70	8.8	13.2	14	19.0	0.950
Brasco	Protected	May	44	5.9	31.8	15	20.5	0.941
Camungo	Protected	July	108	14.4	21.1	9	9.0	1.000
Cashu	Protected	May	145	13.0	28.2	15	25.3	0.982
Garza	Protected	July	218	28.1	34.0	6	17.0	1.000
Juarez	Protected	May	222	29.6	92.0	18	24.0	0.991
Lagarto	Protected	July	245	30.6		14	11.5	0.994
Maisal	Protected	June	39	2.8		12	18.5	0.920
Nueva22	Protected	July	17	2.1	5.7	6	13.0	0.885
Otorongo	Protected	July	232	33.1	36.5	9	7.5	0.998
Salvador	Protected	May	181	23.6	34.6	11	15.0	0.995
Huitoto	Mined	July	31	2.2		14	25.5	0.911
Bajo04	Mined	July	23	2.9	7.1	9	24.5	0.871
Bajo06	Mined	May	38	4.8	8.2	9	13.0	0.935
Bajo07	Mined	July	12	2.7		8	12.0	0.735
Bajo09	Mined	May	14	1.1	8.1	7	8.4	0.836
Bajo10	Mined	May	23	2.9	8.7	13	11.5	0.891
Bajo11	Mined	July	36	5.0	7.3	10	11.5	0.973
Bajo11a	Mined	May	39	4.3	11.3	11	11.0	0.952
Bajo12	Mined	September	78	9.8	5.1	10	10.1	0.994
Bajo16	Mined	July	18	1.1	7.1	6	15.5	0.891

1- S_{all}^{c} - The total number of sampled species in each lake

2- S_{jack}^{c} - The first jackknifing estimator (Gotelli and Colwell, 2011) of species

3- Sampling completeness calculated by the iNext function (Hsieh et al., 2016).

Table S3. Taxonomic composition, total catch, morphometrics and life history information of fish studied in tropical oxbow lakes. Resilience and vulnerability scores are based on Froese and Pauly (2017). Feeding strategies classification is based on sources cited. Data represents fish collected during 2018-2019 in 22 oxbow lakes in Madre de Dios Province, Peru.

Family Species	Total catch	Mean Weight (kg)	Mean length (cm)	IUCN Red List status	Trophic level	Resilience	Vulnerability	Feeding guild	Reference
Acestrorhynchidae									
Acestrorhynchus falcatus (Bloch, 1794)	11	0.08	18.6	Not evaluated	4.2	High	28	Carnivore	(Brosse et al., 2011)
Anostomidae									
Leporinus friderici (Bloch, 1794)	1	0.55	32.7	Not evaluated	3.3	Medium	38	Omnivore	(Pouilly et al., 2003)
Leporinus sp.	5	0.38	28.2					Omnivore	
Leporinus trifasciatus (Steindachner, 1876)	10	0.48	32	Not evaluated	2	Medium	36	Omnivore	(Siqueira-Souza et al., 2017)
*Schizodon fasciatus (*Spix & Agassiz, 1829)	128	0.44	31.3	Not evaluated	2.5	Medium	26	Detritivore	(Freitas et al., 2013)
Auchenipteridae									
Auchenipterus brachyurus (Cope, 1878)	3	0.37	34.2	Not evaluated	3.5	High	26		
Auchenipterus sp.	1	0.14	25.5						
Bryconidae									
Brycon amazonicus (Spix & Agassiz, 1829)	1	0.45	30.2	Least Concern	3	High	30	Omnivore	(Froese and Pauly, 2017)
Calophysidae									
Calophysus macropterus (Lichtenstein, 1819)	1	1.34	49	Not evaluated	3.2	High	30	Carnivore	(Froese and Pauly, 2017)
Characidae									
Charax caudimaculatus	22	0.09	17.7	Not	3.7		10	Omnivore	(de Mérona

Family Species	Total catch	Mean Weight (kg)	Mean length (cm)	IUCN Red List status	Trophic level	Resilience	Vulnerability	Feeding guild	Reference
(Lucena, 1987)				evaluated					et al., 2008)
Roeboides affinis (Günther, 1868)	1	0.02	12	Not evaluated	3.7		10	Omnivore	(Novakowski et al., 2008)
Roeboides myersii (Gill, 1870)	5			Not evaluated	4.2		12	Omnivore	(Pouilly et al., 2003)
Tetragonopterus argenteus (Cuvier, 1816)	3	0.07	13.8	Not evaluated	3.2		10	Omnivore	(Santos and others, 2013)
Cichlidae									
Astronotus ocellatus (Agassiz, 1831)	2	0.22	21.1	Not evaluated	2.8	High	36	Carnivore	(Froese and Pauly, 2017)
Cichlasoma boliviense (Kullander, 1983)	4			Not evaluated	3.3	High	15	Omnivore	Personal observation
Satanoperca jurupari (Heckel, 1840)	1	0.08	15.3	Not evaluated	3.1	High	25	Detritivore	(Brosse et al., 2011)
Curimatidae									
Potamorhina altamazonica (Cope, 1878)	271	0.26	24.6	Not evaluated	2		23	Detritivore	(Freitas et al., 2013)
Psectrogaster rutiloides (Kner, 1858)	4	0.08	15.5	Not evaluated	2		12	Detritivore	(Röpke et al., 2019)
Steindachnerina sp.	6					High	10	Detritivore	(Pouilly et al., 2006)
Cynodontidae									
Cynodon gibbus (Spix & Agassiz, 1829)	2	0.12	20	Not evaluated	4.5		29	Carnivore	(Froese and Pauly, 2017)
Hydrolycus scomberoides (Cuvier, 1816)	6	0.35	32	Not evaluated	4.5			Carnivore	(Froese and Pauly, 2017)

Family Species	Total catch	Mean Weight (kg)	Mean length (cm)	IUCN Red List status	Trophic level	Resilience	Vulnerability	Feeding guild	Reference
Rhaphiodon vulpinus (Spix & Agassiz, 1829)	7	0.58	43.4	Not evaluated	4.5		51	Carnivore	(Gonzalez and Vispo, 2002)
Doradidae									
Megalodoras uranscopus (Eigenmann & Eigenmann, 1888)	6	0.81	37	Not evaluated	2.7	Medium	39	Omnivore	(Froese and Pauly, 2017)
Oxydoras niger (Valenciennes, 1821)	1	7.34	91	Not evaluated	2.8	Low	63	Omnivore	(Froese and Pauly, 2017)
Pterodoras granulosus (Valenciennes, 1821)	1	0.59	35.3	Not evaluated	2.6	Medium	52	Omnivore	(de Mérona et al., 2008)
Erythrinidae									
Hoplias malabaricus (Bloch, 1794)	13	0.49	34.6	Not evaluated	4.5	Low	36	Carnivore	(Röpke et al., 2016)
Loricariidae									
Hypostomus pyrineusi (Miranda-Ribeiro 1920)	1	0.23	24.8	Not evaluated			14	Detritivore	(Pereira et al., 2017)
Pterygoplichthys disjunctivus (weber, 1991)	16			Not evaluated		Medium	31	Detritivore	(Pereira et al., 2017)
Pimelodidae									
Hypophthalmus edentatus (Spix & Agassiz, 1829)	5	0.39	32.1	Not evaluated	2.9	Medium	37	Detritivore	(de Mérona et al., 2008)
Pimelodus blochii (Valenciennes, 1840)	2	0.1	23.6	Not evaluated	3.1	High	27	Carnivore	(Pereira et al., 2017)
Pimelodus maculatus (La Cepède, 1803)	3	0.43	14.7	Not evaluated	2.9	Medium	34	Omnivore	(Lima-Junior and Goitein, 2003)

Family Species	Total catch	Mean Weight (kg)	Mean length (cm)	IUCN Red List status	Trophic level	Resilience	Vulnerability	Feeding guild	Reference
Pimelodus sp.	3	0.19	24.7						
Pseudoplatystoma punctifer (Castelnau, 1855)	2	0.6	47.1	Not evaluated	4.3	Low	72	Carnivore	(Santos and others, 2013)
Pristigasteridae									
Pellona castelnaeana (Valenciennes, 1847)	1		32.4	Least concern	3.7	High	55	Omnivore	(Gonzalez and Vispo, 2002)
Pellona flavipinnis (Valenciennes, 1836)	1			Least concern	4.5	Medium	48	Carnivore	(Gonzalez and Vispo, 2002)
Prochilodontidae									
Prochilodus nigricans (Agassiz, 1829)	69	0.33	27.2	Not evaluated	2.4	Medium	32	Detritivore	(de Mérona et al., 2008)
Rhamphichthyidae									
(Rhamphichthys marmoratus (Castelnau, 1855)	1	0.66	77	Not evaluated	3.2		30		
Sciaenidae									
Plagioscion squamosissimus (Heckel, 1840)	102	0.47	33.3	Least concern	4.4	Medium	62	Omnivore	(Pereira et al., 2017)
Serrasalmidae									
Colossoma macropomum (Cuvier,1818)	1	1.85	43.5	Not evaluated	2	Medium	47	Omnivore	(Froese and Pauly, 2017)
Mylossoma aureum (Agassiz, 1829)	1	0.04	11.3	Not evaluated	2.5	High	12		

Family Species	Total catch	Mean Weight (kg)	Mean length (cm)	IUCN Red List status	Trophic level	Resilience	Vulnerability	Feeding guild	Reference
Mylossoma duriventre (Cuvier, 1818)	16	0.26	20.7	Not evaluated	2.8	High	21	Omnivore	(Freitas et al., 2013)
Pristobrycon sp.	1			Not evaluated	4	High	10	Carnivore	(Freitas et al., 2013)
Pygocentrus nattereri (Kner, 1858)	40	0.37	22.6	Not evaluated	3.7	Medium	27	Carnivore	(Pouilly et al., 2003)
Serrasalmus maculatus (Kner, 1858)	473	0.21	20.9	Not evaluated	4.1	High	23	Carnivore	(Santos and others, 2013)
Serrasalmus rhombeus (Linnaeus, 1766)	348	0.13	17.3	Not evaluated	4	High	33	Carnivore	(Pouilly et al., 2003)
Serrasalmus sp.	7	0.12	16.8					Carnivore	
Serrasalmus spilopleura (Kner, 1860)	262	0.13	16.6	Not evaluated	3.2	High	21	Carnivore	Personal observation
Synbranchidae									
Synbranchus marmoratus (Bloch, 1795)	1	0.98	91	Least Concern	2.8	Very Low	83	Carnivore	(Mérigoux and Ponton, 1998)
Triportheidae									
Triportheus albus (Cope,1862)	2	0.05	14.4	Not evaluated	3.4	High	17	Omnivore	(Freitas et al., 2013)
Triportheus angulatus (Spix & Agassiz, 1829)	21	0.17	21.1	Not evaluated	2.7		19	Omnivore	(Freitas et al., 2013)

Table S4. Permutational MANOVA results of two models assessing the effects of abiotic and biotic variables on fish assemblages, using the Bray-Curtis distance metric, in oxbow lakes of the Madre de Dios province, Peru.

Variable	*Df*	*MS*	R^2	*F*	*P*
Mining activity model					
Size	1	0.261	0.048	1.04	0.38
Dissolved oxygen	1	0.336	0.061	1.34	0.19
Transparency	1	0.517	0.094	2.07	0.04*
NDVI	1	0.245	0.045	0.98	0.42
Otter occurrence	1	0.353	0.064	1.41	0.17
Mining intensity	1	0.281	0.051	0.13	0.32
Residual	13	3.076	0.636		
Fishing activity model					
Size	1	0.261	0.048	1.20	0.27
Dissolved oxygen	1	0.336	0.061	1.55	0.13
Transparency	1	0.517	0.094	2.42	0.03*
NDVI	1	0.245	0.045	1.13	0.31
Otter occurrence	1	0.352	0.064	1.63	0.11
Fishing intensity	1	0.741	0.135	3.42	0.003*
Residual	14	3.029	0.553		

Table S5. Species, feeding guilds, and a comparison of effort-corrected abundances for the 10 most abundant fish in oxbow lakes. For each species, the F ratio and P-value of a one-way ANOVA between mined and protected lakes is given. Data were collected in oxbow lakes of the Madre de Dios province, Peru during 2018-2019.

Species	Feeding guild	CPUE mined	CPUE protected	ratio	ANOVA $F_{(2,20)}$	P
Charax sp.	Omnivore	0.05	0.18	3.49	135.7	< 0.001
Hypostomus pyreneusi (Miranda-Ribeiro 1920)	Detritivore	0.16	0.14	0.89	61.4	< 0.001
Plagioscion squamosissimus (Heckel, 1840)	Carnivore	0.13	0.95	7.04	61.8	< 0.001
Potamorhina altamazonica (Cope, 1878)	Detritivore	1.31	1.53	1.17	280.7	< 0.001
Prochilodus nigricans (Agassiz, 1829)	Detritivore	0.16	0.57	3.70	126.7	< 0.001
Pygocentrus nattereri (Kner, 1858)	Carnivore	0.16	0.27	1.71	118.9	< 0.001
*Schizodon fasciatus (*Spix & Agassiz, 1829)	Detritivore	0.07	1.3	20.91	19.8	< 0.001
Serrasalmus maculatus (Kner, 1858)	Carnivore	0.48	4.54	9.55	135.1	< 0.001
Serrasalmus rhombeus (Linnaeus, 1766)	Carnivore	0.16	3.54	22.83	78.5	< 0.001
Serrasalmus spilopleura (Kner, 1860)	Carnivore	0.18	2.60	14.82	98.3	< 0.001

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