Unveiling the impacts of the Largest Amazonian Hydropower Endeavor on fish communities through long-term underwater cameras surveillance

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Appendix A. Supplementary data

Table S1

Number of Baited Remote Underwater Video (BRUV) systems deployed in each year, sector, and habitat.

Year	Upstream		Main reservoir		Reduced flow		Downstream	
	Beaches	Rapids	Beaches	Rapids	Beaches	Rapids	Beaches	Rapids
2014	10	10	10	10	10	10	10	5
2015	10	10	9	8	10	7	10	5
2016	9	9	5	1	10	10	10	5
2017	9	9	5	0	9	9	10	5
2018	7	10	7	0	11	9	10	5
2019	6	10	6	0	10	10	9	5
2020	10	10	0	1	8	9	10	5

Table S2

Model structure of the spatial-temporal models used to fit α-diversity (richness), MaxN (proxy for abundance), β-diversity, turnover, nestedness, γ-diversity, local contribution to β-diversity (LCBD), and environmental condition data. The code presented in the "fixed and random effects" column follows the syntax structure of the mgcv R package (Wood 2017). Distance = Distance to the Pimental dam.

Response variable	Fixed and random effects	Distribution
α-diversity (Richness)	te(Year, Distance, bs=c("tp", "tp"), k=c(7,8), m=2) + te(Year, Distance, by=Habitat, bs=c("tp", "tp"), k=c(7,8), m=1) + s(Habitat, bs="re",k=2)	Poisson
MaxN	te(Year, Distance, bs=c("tp", "tp"), k=c(7,8), m=2) + te(Year, Distance, by=Habitat, bs=c("tp", "tp"), k=c(7,8), m=1) + s(Habitat, bs="re",k=2)	Negative binomial
β-diversity (Ružička index)	s(Year, k=7, bs="tp", m=2) + s(Habitat, k=2, bs="re")	Gaussian
Turnover	s(Year, k=7, bs="tp", m=2) + s(Habitat, k=2, bs="re")	Gaussian
Nestedness	s(Year, k=7, bs="tp", m=2) + s(Habitat, k=2, bs="re")	Gaussian
γ-diversity	s(Year, k=7, bs="tp", m=2) + s(Habitat, k=2, bs="re")	Poisson
LCBD	te(Year, Distance, bs=c("tp", "tp"), k=c(7,8), m=2) + te(Year, Distance, by=Habitat, bs=c("tp", "tp"), k=c(7,8), m=1) + s(Habitat, bs="re",k=2)	Gaussian
Environmental conditions	te (Year, Distance, bs= c("tp", "tp"), k= c(5, 6))	Gaussian/Poisson

Table S3

Principal component (PCA) scores of the physical-chemical and hydrological variables. The total variation explained by each one of the first three PCA axes is provided in parenthesis.

Physical-Chemical variables

	PC1 (41%)	PC2 (28%)	PC3 (23%)
Conductivity	2.22	-2.12	0.48
Turbidity	3.01	0.06	0.42
Dissolved oxygen	-1.22	-2.62	-1.38
pH	-1.44	-0.94	2.77

Hydrological parameters

	PC1 (73%)	PC2 (18%)	PC3 (7%)
Mean monthly flow	-2.31	-1.96	0.56
Lowest flow recorded in the year	-2.68	-1.36	-0.61
Highest flow recorded in the year	-2.71	1.1	-0.86
Annual rate of flow increase	-2.59	1.09	1.3
Length of the wet season	-2.9	0.82	-0.24

Table S4

Summary of the Hierarchical Generalized Additive Models (HGAM) created to explain fish α-diversity (richness), MaxN (proxy for abundance), β-diversity, turnover, nestedness, γ-diversity, local contribution to β-diversity (LCBD), and the environmental variables. The code presented in the "smooth function" column follows the syntax structure of the mgcv R package (Wood 2017). *Full model from Table 1. Distance= Distance to the Pimental dam, Hidrol.PC1= PC1 - Hydrological parameters, Water.PC1= PC1 – Physical-chemical parameters

Model	Smooth functions	edf	Ref. df	Stat	Stat value	Significance	Adj. R2
α-diversity	te(Year, Distance)	11.37	14.67	Chi.sq	55.67	<0.001	0.60
	te(Year, Distance):Beach	5.38	54.00	Chi.sq	25.00	<0.001	
	te(Year, Distance):Rapids	15.27	41.00	Chi.sq	37.47	<0.001	
	s(Habitat)	0.99	1.00	Chi.sq	87.57	<0.001	
α-diversity *	s(Hidrol.PC1)	4.48	5.44	Chi.sq	26.12	<0.001	0.50
	s(Water.PC1)	4.77	5.78	Chi.sq	17.34	=0.007	
	s(Fishery yield)	2.55	3.08	Chi.sq	4.06	=0.23	
	s(Mei)	1.00	1.00	Chi.sq	4.20	=0.04	
	s(Year)	1.00	1.00	Chi.sq	64.15	<0.001	
	s(Distance)	3.96	4.64	Chi.sq	12.57	=0.01	
	s(Habitat)	0.99	1.00	Chi.sq	101.26	<0.001	
MaxN	te(Year, Distance)	6.97	7.51	Chi.sq	20.95	=0.006	0.62
	te(Year, Distance):Beach	31.03	52.00	Chi.sq	162.33	<0.001	
	te(Year, Distance):Rapids	27.91	41.00	Chi.sq	126.14	<0.001	
	s(Habitat)	0.95	1.00	Chi.sq	20.33	<0.001	
MaxN*	s(Hidrol.PC1)	6.354	7.511	Chi.sq	32.854	<0.001	0.43
	s(Water.PC1)	7.111	8.453	Chi.sq	91.286	<0.001	
	s(Fishery yield)	1.74	2.11	Chi.sq	3.995	=0.12	
	s(Mei)	1	1	Chi.sq	0.033	=0.85	
	s(Year)	1	1	Chi.sq	51.193	<0.001	
	s(Distance)	5.451	5.809	Chi.sq	132.933	<0.001	
	s(Habitat)	0.915	1	Chi.sq	10.783	<0.001	
β-diversity	s(Year)	1.27	1.49	F	9.04	=0.01	0.53
	s(Habitat)	0.76	1.00	F	3.22	=0.06	
Turnover	s(Year)	1.00	1.00	F	1.82	=0.20	0.06
	s(Habitat)	0.00	1.00	F	0.00	=0.84	
Nestedness	s(Year)	1.00	1.00	F	1.82	=0.20	0.06
	s(Habitat)	0.00	1.00	F	0.00	=0.84	
γ-diversity	s(Year, k=7, bs="tp", m=2)	1.00	1.00	Chi.sq	6.50	=0.01	0.57
	s(Habitat, k=2, bs="re")	0.00	1.00	Chi.sq	0.00	=0.67	
LCBD	te(Year,Distance)	4.83	5.77	F	3.37	=0.006	0.23

Model	Smooth functions	edf	Ref. df	Stat	Stat value	Significance	Adj. R2
	t2(Year,Distance, Habitat)	0.93	25.00	F	0.58	<0.001	
Conductivity	te(Year,Distance)	9.08	10.18	F	2.55	=0.014	0.30
pH	te(Year,Distance)	4.86	5.74	F	3.23	=0.01	0.22
Turbidity	te(Year,Distance)	3.50	3.91	F	2.30	=0.06	0.11
Dissolved Oxygen	te(Year,Distance)	7.62	8.48	F	10.20	<0.001	0.62
Fishery yield	te(Year,Distance)	15.25	19.55	F	6.53	<0.001	0.70
MEI	te(Year,Distance)	8.83	8.99	F	16.05	<0.001	0.71
Mean Monthly Flow	te(Year,Distance)	8.81	10.12	F	15.26	<0.001	0.73
Lowest Flow Recorded in the Year	te(Year,Distance)	8.11	8.77	F	34.24	<0.001	0.84
Highest Flow Recorded in the Year	te(Year,Distance)	9.81	11.25	F	9.59	<0.001	0.66
Annual Rate of Flow Increase	te(Year,Distance)	18.91	22.82	F	5.59	<0.001	0.70
Length of the Wet Season	te(Year,Distance)	25.82	28.30	Chi.sq	482.00	<0.001	0.51

Table S5

List of species recorded by Baited Remote Underwater Video (BRUV) in the Middle Xingu River. MaxN and relative MaxN values were provided for each year sampling and habitat, respectively. S total = Total number of species.

Order, Family, Species	Years							Habitat	
	2014	2015	2016	2017	2018	2019	2020	Rapids	Beaches
Characiformes									
Acestrorhynchidae									
Acestrorhynchus falcatus	0	0	0	0	0	1	0	0	0
Anostomidae									
Anostomoides passionis	15	21	16	5	4	7	5	0.003	0
Hypomasticus julii	75	42	34	75	26	4	29	0.014	0
Laemolyta fernandezi	2	0	0	0	0	0	0	0	0
Laemolyta proxima	0	0	0	0	1	13	0	0.001	0
Leporellus vittatus	1	1	0	0	0	0	0	0	0
Leporinus aff. fasciatus	124	141	190	288	204	6	163	0.046	0.01
Leporinus brunneus	41	20	11	27	15	16	13	0.007	0
Leporinus desmotes	5	3	2	6	10	0	4	0.001	0
Leporinus friderici	24	7	86	26	2	11	11	0.004	0
Leporinus gr. megalepis	0	1	0	0	0	0	0	0	0
Leporinus maculatus	169	172	39	242	87	151	142	0.044	0.01
Leporinus sp. 2	16	17	0	29	5	1	0	0.003	0
Leporinus tigrinus	55	22	42	22	21	122	54	0.013	0
Schizodon vittatus	1	1	0	2	0	0	0	0	0
Bryconidae									
Brycon aff. pesu "adiposa hialina"	81	336	90	74	3	0	104	0.02	0.03
Brycon aff. pesu "adiposa preta"	37	52	29	46	23	61	34	0.002	0.03
Brycon falcatus	0	0	0	7	3	44	3	0.001	0
Characidae									
Astyanax bimaculatus	0	0	55	0	0	0	0	0	0
Caiapobrycon sp.	0	12	0	65	0	0	0	0.001	0.01
Characidae sp. "pinta pedunculo"	2065	728	220	40	65	0	0	0.128	0.05
Creagrutus spp.	140	577	245	20	0	18	0	0.016	0.08
Hemigrammus sp. "transparente"	273	351	0	72	211	30	81	0.029	0.05
Hemigrammus spp.	0	0	0	0	0	62	0	0.003	0
Hyphessobrycon pulchripinnis	0	0	0	0	0	18	0	0.001	0
Jupiaba aconthogaster	0	0	0	0	0	28	0	0	0
Knodus heteresthes	0	0	0	0	0	10	0	0	0

Order, Family, Species	Years							Habitat	
	2014	2015	2016	2017	2018	2019	2020	Rapids	Beaches
Moenkhausia celibela	208	963	10	0	0	72	0	0.054	0.02
Moenkhausia gr. lepidura	352	499	321	216	267	71	568	0.083	0.07
Moenkhausia heikoi	287	192	120	35	20	0	0	0.031	0
Moenkhausia xinguensis	1233	976	624	324	460	0	113	0.138	0.1
Crenuchidae									
Characidium gr. fasciatum	8	1	0	0	0	0	0	0	0
Ctenolucidae									
Boulengerella cuvieri	46	69	20	50	22	11	19	0.006	0.01
Cynodontidae									
Hydrolycus armatus	5	4	0	0	0	1	0	0	0
Hydrolycus tatauaia	7	1	0	0	0	0	0	0	0
Hemiodontidae									
Argonectes robertsi	3	5	2	5	11	3	4	0	0
Bivibranchia velox	1	0	0	0	0	0	0	0	0
Hemiodus tocantinensis	0	0	0	0	0	81	0	0.002	0
Hemiodus unimaculatus	30	8	6	17	23	28	18	0.004	0
Hemiodus vorderwinckleri	95	94	51	158	105	3	56	0.025	0
Iguanodectidae									
Bryconops alburnoides	671	1589	737	253	280	552	144	0.106	0.25
Bryconops caudomaculatus	0	7	0	0	0	13	0	0	0
Bryconops cf.affinis	0	0	0	0	0	0	40	0	0.01
Prochilodontidae									
Prochilodus nigricans	14	36	20	31	15	2	8	0.003	0
Semaprochilodus brama	4	0	30	16	15	32	12	0.002	0.01
Serrasalmidae									
Acnodon normani	87	65	57	41	76	70	40	0.011	0.03
Myleus setiger	546	272	398	160	168	95	99	0.045	0.1
Myloplus arnoldi	3	4	5	8	6	7	70	0.003	0
Myloplus rhomboidalis	14	11	6	0	0	1	0	0.001	0
Myloplus rubripinnis	0	0	0	1	0	0	0	0	0
Myloplus schomburgkii	14	25	41	41	21	22	59	0.008	0
Serrasalmus manueli	17	7	27	1	0	3	0	0.001	0
Serrasalmus rhombeus	30	34	190	164	102	47	73	0.014	0
Tometes sp.	83	177	52	236	195	1	200	0.032	0.03
Triportheidae									
Agoniates halecinus	0	2	10	0	0	1	0	0.001	0
Triportheus albus	0	0	8	3	1	0	3	0	0
Gymnotiformes									
Gymnotidae									
Electrophorus electricus	0	1	0	1	1	0	0	0	0
Myliobatiformes									
Potamotrygonidae									

Order, Family, Species	Years							Habitat	
	2014	2015	2016	2017	2018	2019	2020	Rapids	Beaches
Paratrygon aireba	0	0	0	0	0	1	0	0	0
Potamotrygon leopoldi	10	12	15	14	9	11	7	0.003	0
Potamotrygon motoro	0	0	0	0	0	1	0	0	0
Potamotrygon orbignyi	4	3	2	6	1	0	1	0	0
Perciformes									
Cichlidae									
Apistogramma gephyra	0	0	0	0	0	0	4	0	0
Cichla melaniae	15	36	26	96	17	24	21	0.006	0
Cichla monoculus	0	1	0	0	0	0	0	0	0
Cichla pinima	5	2	15	16	15	5	23	0.003	0
Crenicichla gr. lugubris	34	30	31	66	29	36	31	0.011	0
Crenicichla percna	4	3	0	0	0	0	0	0	0
Geophagus altifrons	19	18	45	40	54	2	45	0.007	0.01
Geophagus argyrostictus	25	38	136	84	104	9	66	0.021	0
Retroculus xinguensis	3	0	2	3	31	0	11	0.001	0
Satanoperca sp.	5	0	0	0	0	0	0	0	0
Teleocichla centrarchus	0	1	4	0	0	0	0	0	0
Teleocichla cinderella	78	120	172	98	151	127	140	0.03	0.03
Teleocichla gephyrogramma	1	0	27	0	0	0	0	0.001	0
Teleocichla sp. "preta"	1	1	3	0	0	1	1	0	0
Sciaenidae									
Pachyurus junki	0	1	0	1	0	0	1	0	0
Plagioscion squamosissimus	0	0	1	0	0	0	0	0	0
Siluriformes									
Doridídae									
Leptodoras hasemani	0	0	0	0	0	1	0	0	0
Loricariidae									
Baryancistrus sp. "verde"	0	0	0	5	0	2	0	0	0
Baryancistrus spp.	0	0	0	10	0	0	2	0.001	0
Baryancistrus xanthellus	5	6	11	2	20	2	4	0.002	0
Hopliancistrus sp. "pinta"	1	0	0	0	0	1	0	0	0
Hypostomus hemicochliodon	0	0	0	0	0	0	3	0	0
Loricaria birindelli	0	1	0	0	0	0	0	0	0
Peckoltia sabaji	1	1	0	0	0	0	0	0	0
Spectracanthicus zuanoni	1	0	0	0	0	0	0	0	0
Pimelodidae									
Phractocephalus hemioliopterus	6	1	0	0	0	0	1	0	0
Pimelodus blochii	0	0	0	5	0	0	0	0	0
Pimelodus ornatus	1	0	0	0	0	0	0	0	0
Pinirampus pirinampu	1	2	4	2	2	0	4	0.001	0
Pseudoplastytoma punctifer	1	4	1	3	5	0	2	0.001	0
Brachyplatystoma	0	0	0	0	0	1	0	0	0

Order, Family, Species	Years							Habitat	
	2014	2015	2016	2017	2018	2019	2020	Rapids	Beaches
filamentosum									
Pseudoplatystoma fasciatum	0	0	0	0	0	3	0	0	0
Trichomycteridae									
Henonemus sp.	0	0	0	0	0	0	5	0	0
Symbranchiformes									
Symbranchidae									
Symbranchus marmoratus	0	0	1	0	0	0	0	0	0
Tetraodontiformes									
Tetraodontidae									
Colomesus asellus	1	3	5	21	2	0	8	0	0
S total	62	62	52	54	46	55	49	52	20

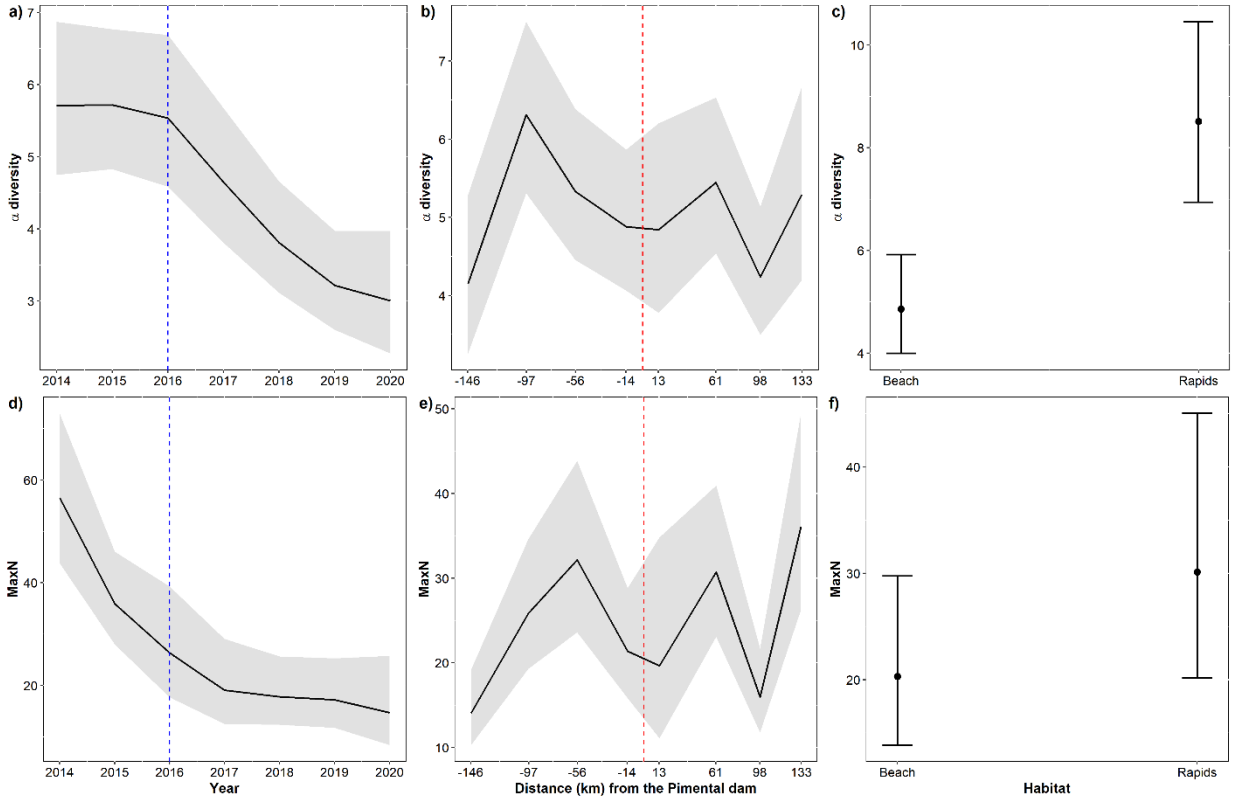

Fig. S1. Marginal effect of the year (a, d), distance to the Pimental dam (b, e), and habitat (c, f) on α-diversity (richness) and MaxN (proxy for abundance). Black lines are the average predictions and the gray ribbons are the standard errors. Vertical blue lines indicate the year when the Belo Monte project started its operations. Horizontal red lines show the location of the Pimental dam.

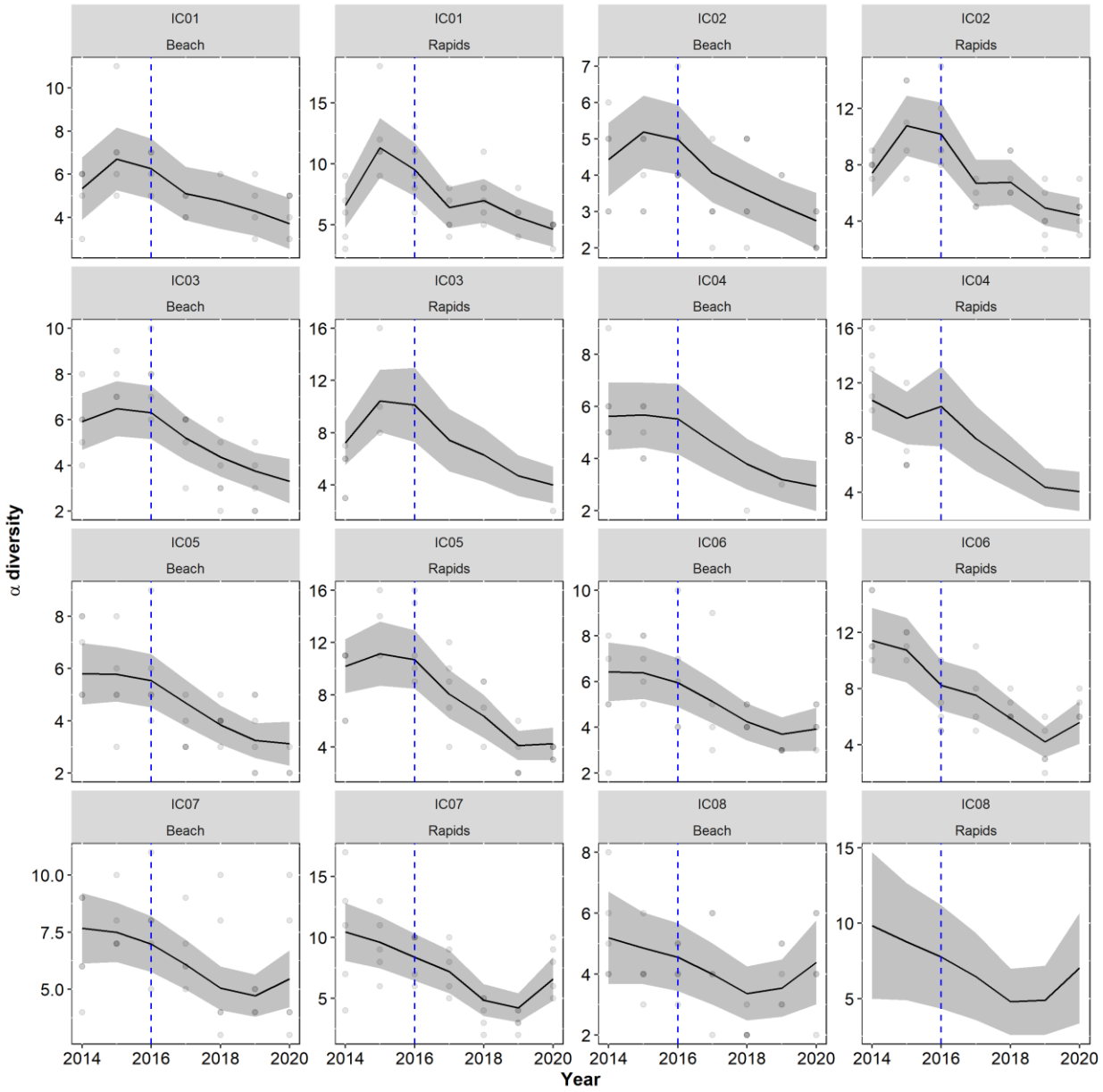

Fig. S2. Variation in α-diversity (richness) across years, sampling sites, and habitats. Black lines are the average predictions of our Hierarchical Generalized Additive Model (HGAM) and the gray ribbons are the standard errors. Vertical blue lines indicate the year when the Belo Monte project started its operations. IC01 to IC02 represent upstream sections not directly affected by reservoir filling; IC03 to IC04 represent sections directly affected by reservoir filling; IC05 to IC06 are situated in the reduced flow sector, and IC07 to IC08 are located in downstream sections unaffected by the reduced flow sector.

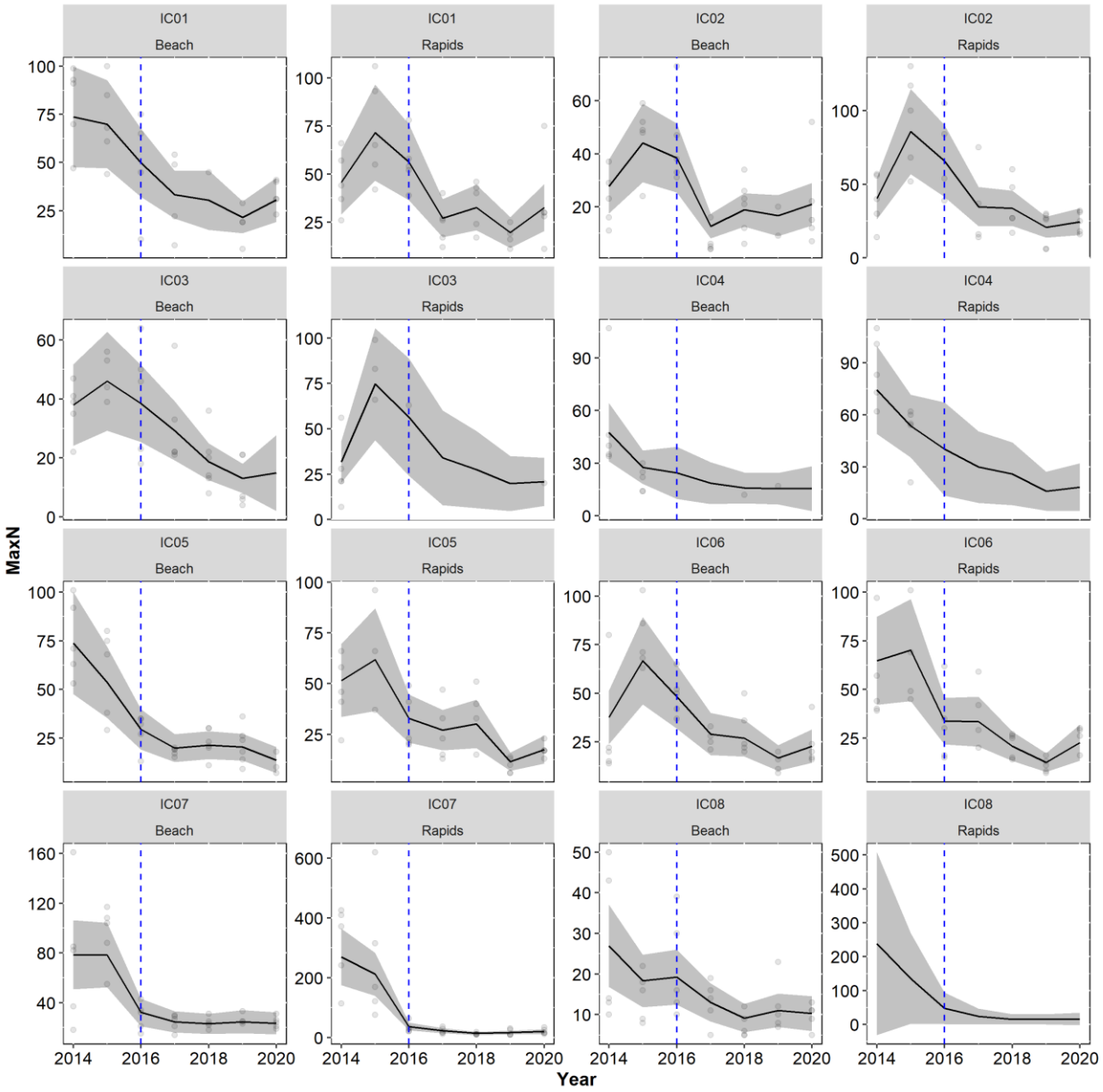

Fig. S3. Variation in MaxN (proxy for abundance) across years, sampling sites, and habitats. Black lines are the average predictions of our Hierarchical Generalized Additive Model (HGAM) and the gray ribbons are the standard errors. Vertical blue lines indicate the year when the Belo Monte project started its operations. IC01 to IC02 represent upstream sections not directly affected by reservoir filling; IC03 to IC04 represent sections directly affected by reservoir filling; IC05 to IC06 are situated in the reduced flow sector, and IC07 to IC08 are located in downstream sections unaffected by the reduced flow sector.

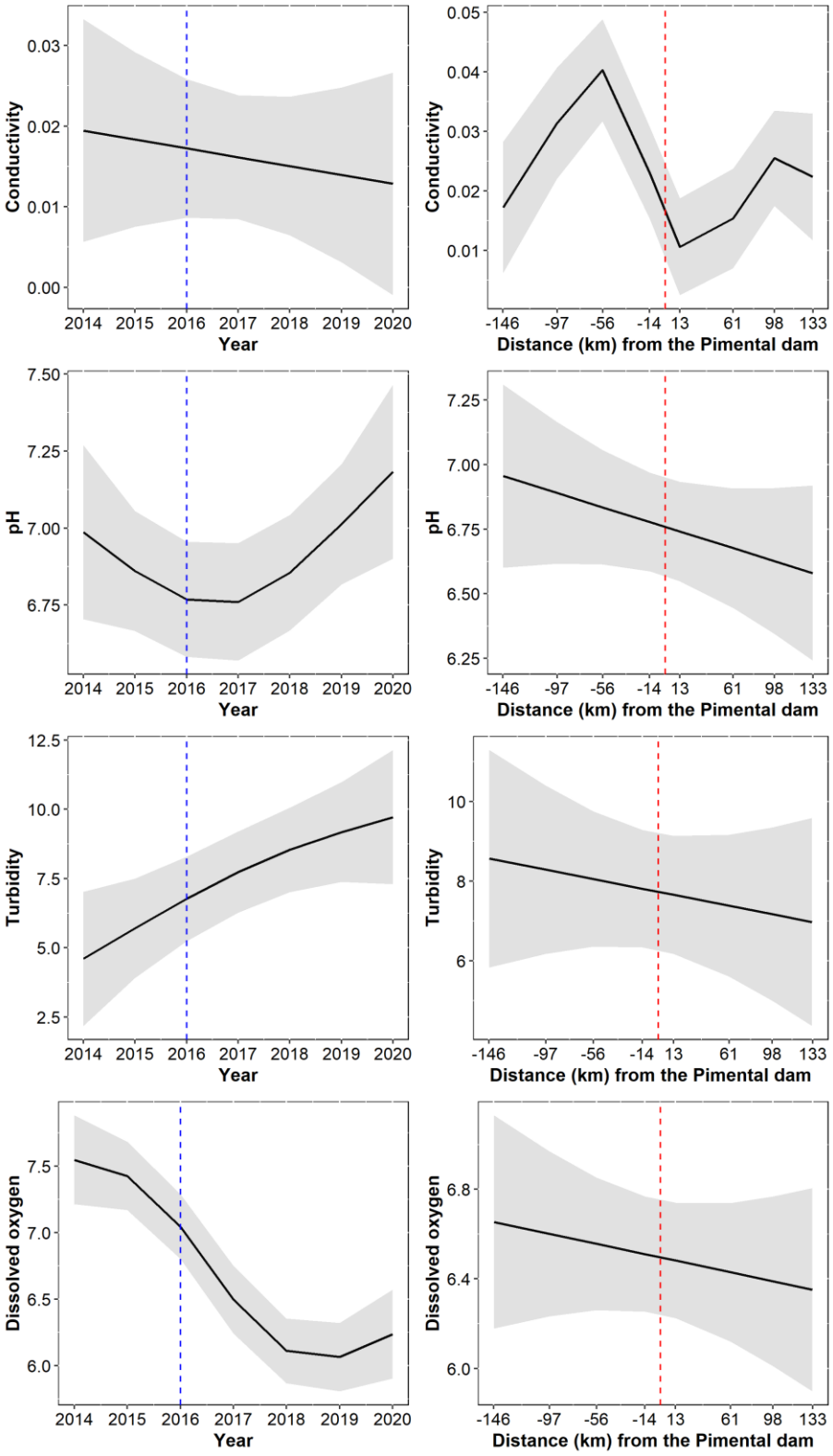

Fig. S4. Marginal effect of year and distance from the Pimental dam on conductivity, pH, turbidity, and dissolved oxygen. Black lines are the average predictions of our Hierarchical

Generalized Additive models (HGAM) and the gray ribbons are the standard errors. Vertical blue lines indicate the year when the Belo Monte project started its operations. Horizontal red lines show the location of the Pimental dam.

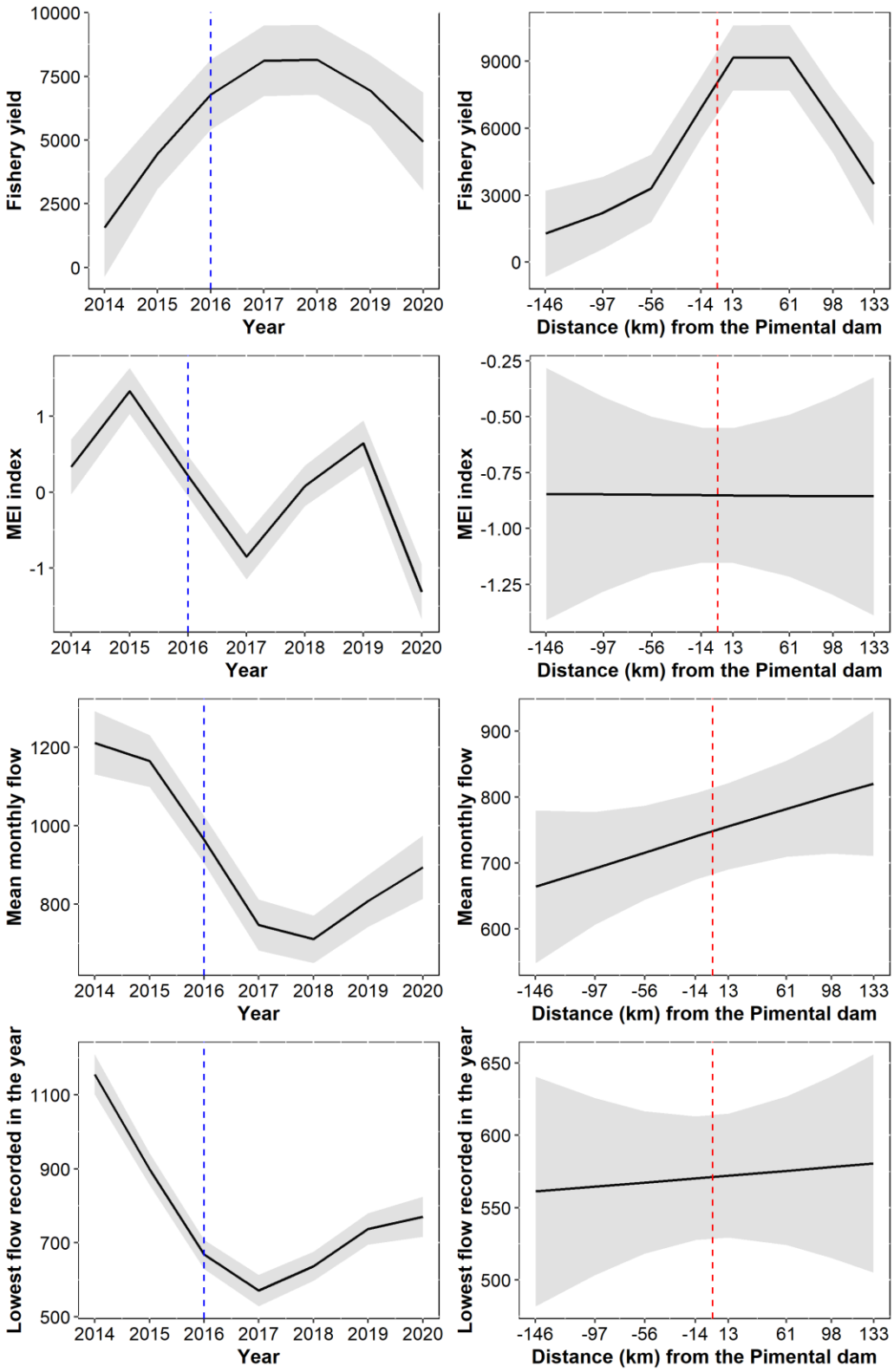

Fig. S5. Marginal effect of year and distance from the Pimental dam on fishery yield, MEI, mean monthly flow, and lowest flow recorded in the year. Black lines are the average predictions of

our Hierarchical Generalized Additive models (HGAM) and the gray ribbons are the standard errors. Vertical blue lines indicate the year when the Belo Monte project started its operations. Horizontal red lines show the location of the Pimental dam.

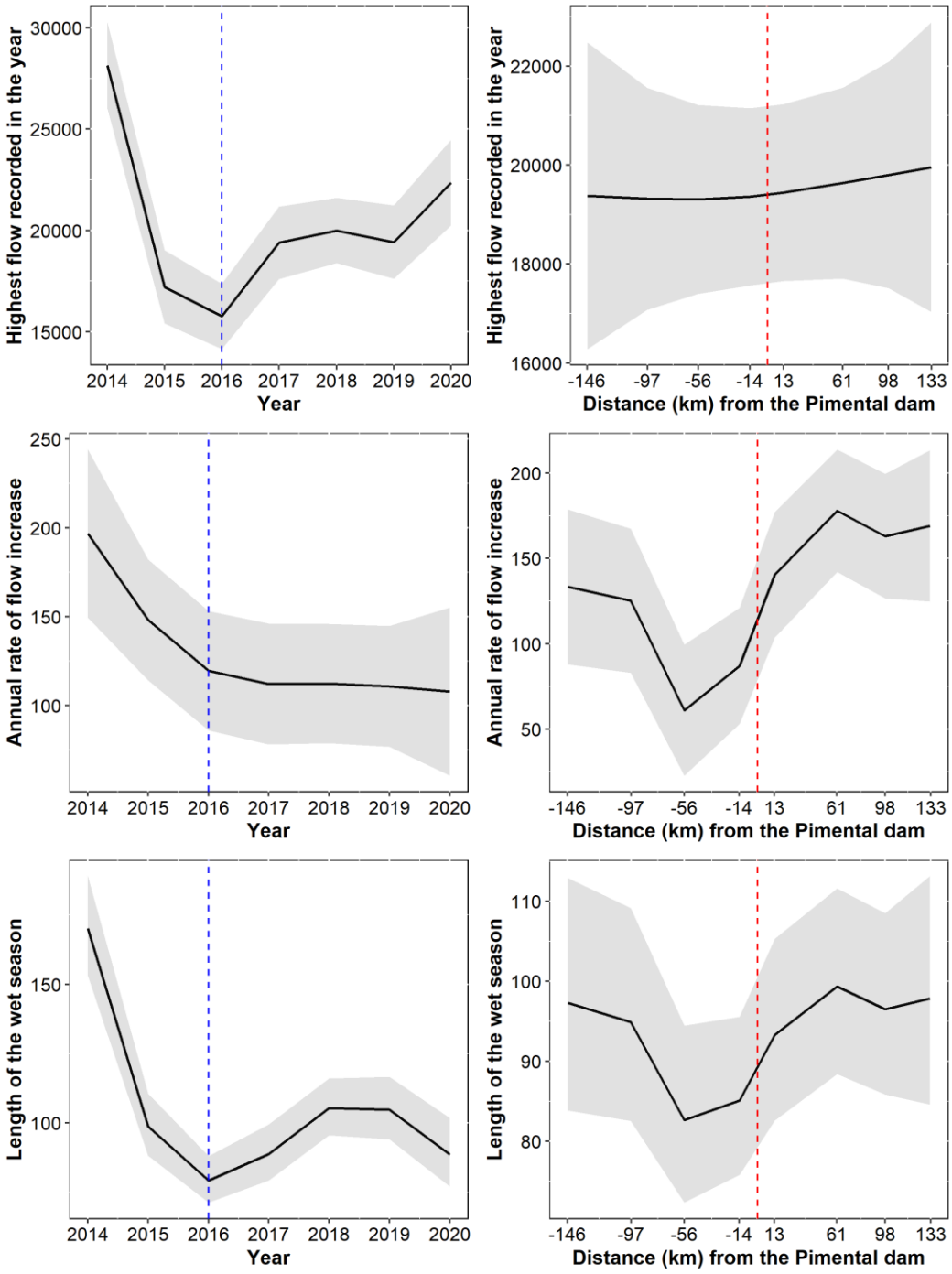

Fig. S6. Marginal effect of year and distance from the Pimental dam on the highest flow recorded in the year, annual rate of flow increase, and length of the wet season. Black lines are the average predictions of our Hierarchical Generalized Additive models (HGAM) and the gray ribbons are

the standard errors. Vertical blue lines indicate the year when the Belo Monte project started its operations. Horizontal red lines show the location of the Pimental dam.

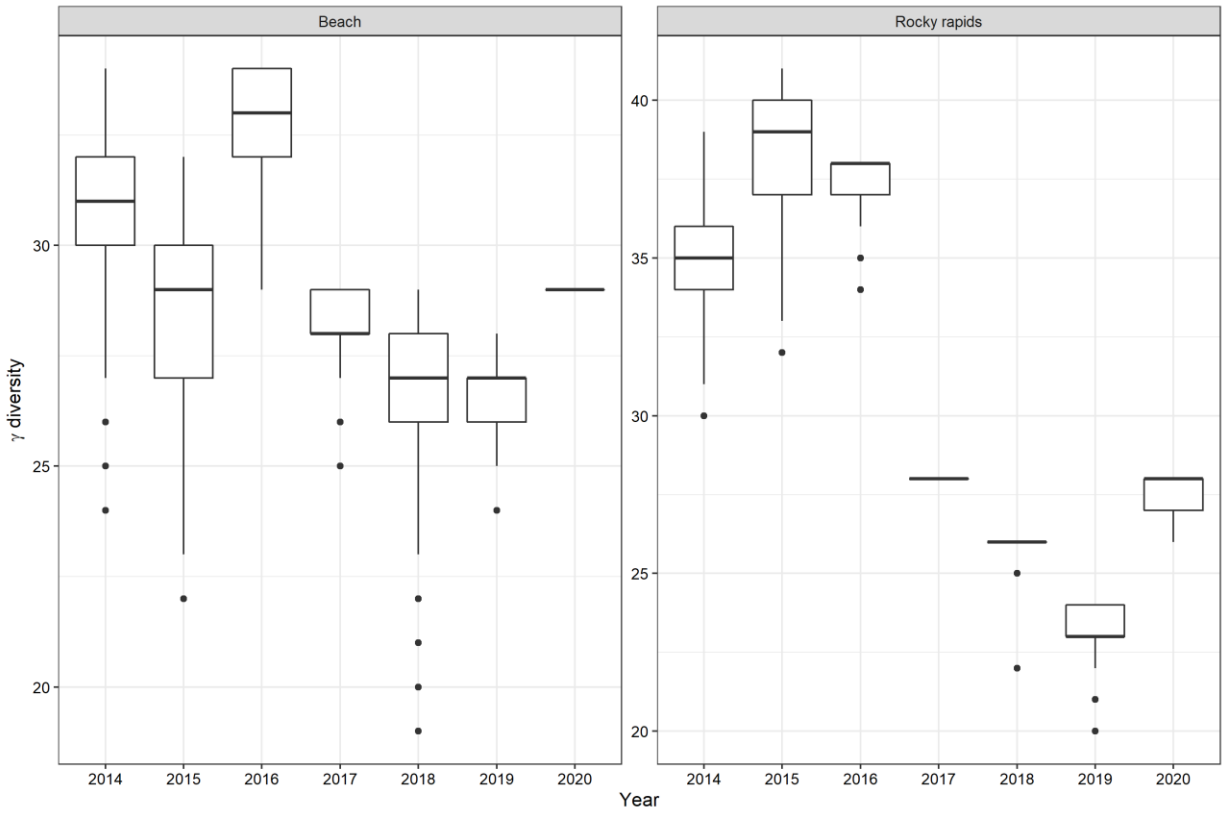

Fig. S7. Variation in γ-diversity across habitats (Beach and rocky rapids) and during the study period. To control for different sample sizes between the years, we conducted a bootstrap approach where we compared the γ-diversity between years using a fixed number of BRUV systems (year with the lowest number of BRUV systems deployed). The bootstrap approach was carried out with 1000 computer iterations.