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Review

Environmental tradeoffs of hydropower dams in the Sekong, Sesan, and Srepok (3S) Rivers of the Lower Mekong Basin

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Supplementary Materials

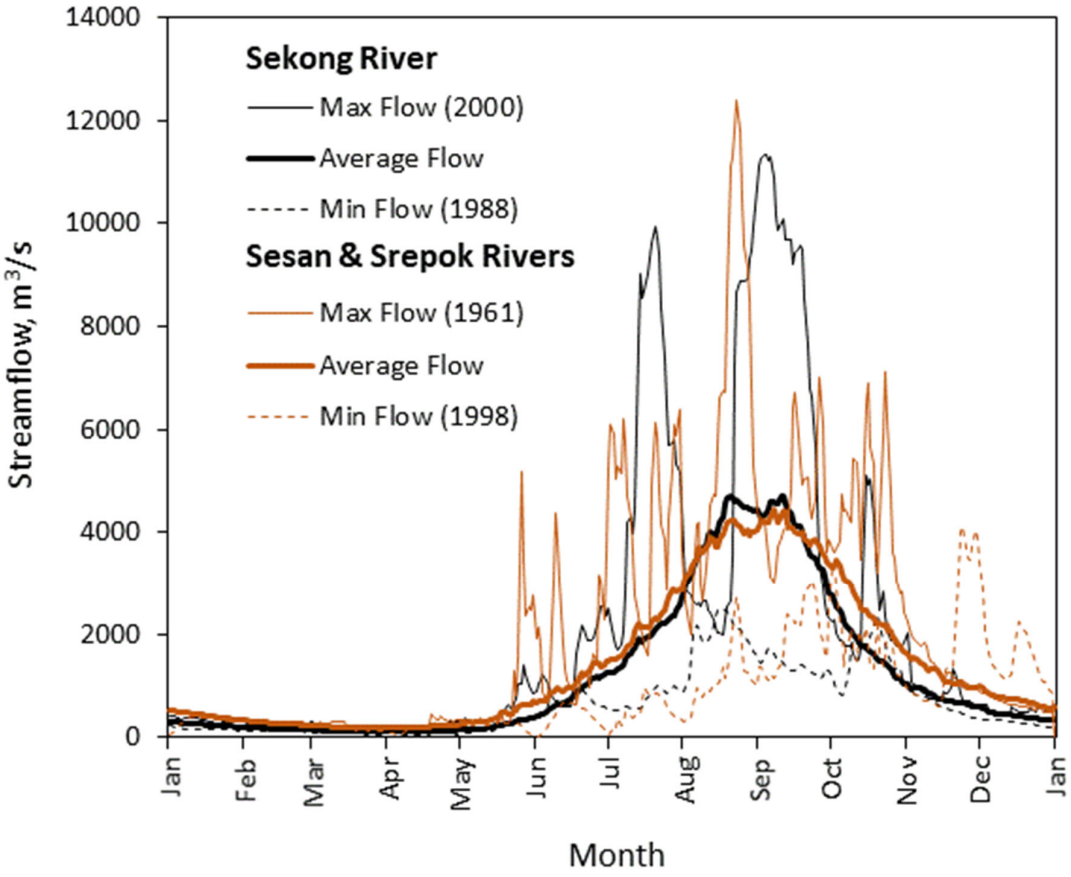

Figure S1. Maximum, average, and minimum streamflow at Chatangoy (Sekong River) and Ban Kamphun (Sesan and Srepok Rivers) gaging stations from 1960 to 2002.

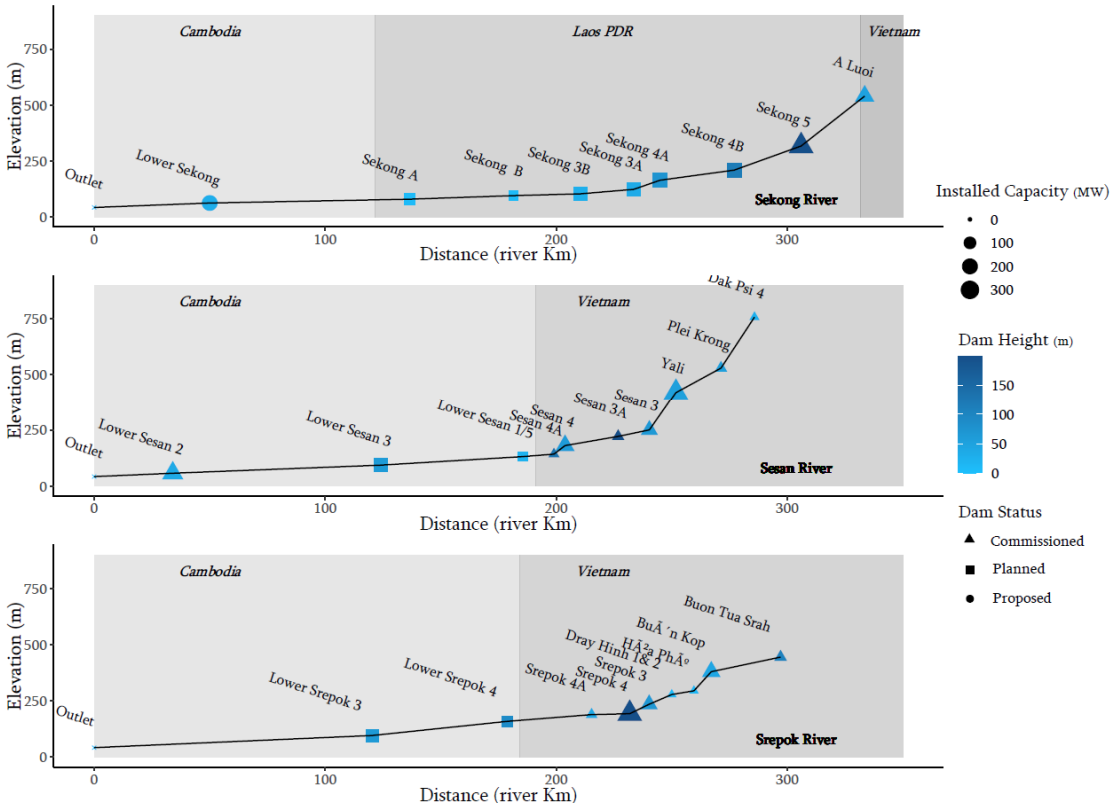

Figure S2. Longitudinal profile of existing, planned, and proposed dams on mainstem Sekong, Sesan, and Srepok Rivers.

Table S1. Dams in the 3S basin and their attributes (data sources: [12, 17, 30, 31]). NA = not available.

Name	Latitude	Longitude	Commercial Operation Date	Mean Q ($m^3 s^{-1}$)	Full Supply Level (m)	Gross storage (Mm^3)	Inundated area at full storage (km^2)	Installed capacity (MW)	Production ($GWh\ yr^{-1}$)
DrayHlinh1	12.6769	107.9133	1990	241	302	2.9	0	12	94
O Chum 2	13.7723	106.9873	1992	3.8	NA	0.1	NA	1	NA
Houayho	14.8931	106.6661	1999	9.5	880	674.1	38.3	150	487
Yali	14.2228	107.7931	2002	262	515	1037.1	64.5	720	3658.6
SeSan3	14.2167	107.7	2006	274	304.5	92	3.4	260	1224.6
SeSan3A	14.1061	107.655	2007	283	239	80.6	8.8	96	479.3
DrayHlinh2	12.6769	107.9133	2007	241	302	2.9	0	16	85
PleiKrong	14.4083	107.8611	2009	128	570	1048.7	53.3	100	417.2
BuonTuaSrah	12.2853	108.0478	2009	102	487.5	787	37.1	86	358.6
BuonKuop	12.5244	107.9314	2009	217	412	73.8	5.6	280	1458.6
SeSan4	13.9667	107.5	2010	328.9	215	893.3	58.4	360	1420.1
SrePok3	12.7542	107.8614	2010	250.6	272	219	17.7	220	1060.2
SrePok4	12.8731	107.7806	2010	273	207	29.3	3.8	80	329.3
SeSan4A	13.9333	107.4664	2011	330	155.2	13.1	1.8	63	296.9
SrePok4A	NA	NA	2013	NA	NA	0.78	NA	64	308.35
XeNamNoy5	15.1639	106.6686	2013	3.6	800	9.8	0.6	20	124
UpperKontum	14.7111	108.2375	2014	16.7	1170	173.7	8.6	250	1056.4
Xekaman-3	15.4361	107.3367	2015	29.6	960	141.5	5.2	250	982.8
Xekaman-1	14.9633	107.1517	2017	175	230	4804	149.8	290	1096
HouayLamphanGnai	15.36	106.4983	2017	6.5	840	480.5	6.8	84.8	264.4
LowerSeSan2	13.5533	106.2	2017	1306	75	1792.5	334.4	400	1953.9
XeKaman2A	15.2169	107.4389	2018	77.5	280	20.8	1.5	64	241.6

XeKaman2B	15.2753	107.45	2018	68.4	370	333	8.6	100	380.5
NamKong2	14.4927	106.8532	2018	45	460	166.2	4.2	66	309.5
Xepian-Xenamnoy	15.0258	106.6056	2019	42.7	786.5	1092	53	410	1748
NamKong1	14.5529	106.7299	2019	42	320	682.7	21.8	150	469
XeKong5	15.975	106.9306	2019	137	487	3300	32.8	330	1201
Xekatam	15.1354	106.5891	2020	12.3	911	126	7.8	68	380
XeKaman4(4A)	15.2244	107.5261	2020	10.2	860	16.5	14.4	54	375
Xekong-4	15.5139	106.7878	2022	205	290	10500	170.3	380	1901
XeKong3up	15.3841	106.7766	2022	240.3	160	95.1	20.8	105	598.7
XeKong3d	15.1221	106.8211	2022	316.4	117	168.4	0	100	375.7
DakEMule	15.555	107.0711	2022	16.1	780	243.1	9.6	130	506
Xesu	14.7083	107.1764	2022	77.2	180	2671	7.2	30	286.2
XeKaman4B	15.3472	107.5358	Planned	7.4	865	21.2	0	0	301
LowerSeSan3	14.0316	107.0236	Planned	330	140	16900	726.9	260	1310.2
PrekLiang1	14.2166	107.2507	Planned	40.2	275	110	1.73	72	324.3
PrekLiang2	14.2833	107.2667	Planned	25.4	495	180	2.09	56	259.6
LowerSrePok3(3A)	13.3883	107.05	Planned	713	120	5863	721	300	1201.4
LowerSrePok4	13.0383	107.45	Planned	378	148	204	33	48	220.7
DucXuyen	12.1428	108.1006	Planned	35.7	560	1749.78	77.3	58	181.3
Sekong	13.7939	106.2544	Proposed	1323	63	NA	93.73	190	557.5
LowerSeSan1	13.8139	107.4614	Proposed	385	141	100.7	16.3	96	485

Table S2. Papers included in review, study system, human and environmental objectives, and decision variables. 3S = Sekong, Sesan, and Srepok Basin; LMB = Lower Mekong Basin; HP = hydropower; GHG = greenhouse gas emissions; SDO = siting, design, and operations.

Source	Study System	Human Objectives	Environmental Objectives	Decision Variables
Annandale, G & Golder Associates. 2013. Technical Memorandum on Options for Sediment Passage through Lower Se San 2 dam. Available at: https://n-h-i.org/wp-content/uploads/2017/02/Technical_Memo_Sediment-Mgmt_LSS2_Annandale_2013.pdf.	3S	HP	Sediment	SDO
Arias, ME, T Piman, H Lauri, TA Cochrane, M Kummu. 2014. Dams on Mekong tributaries as significant contributors of hydrological alterations to the Tonle Sap Floodplain in Cambodia. *Hydrology and Earth System Sciences* 18(12): 5303–5315.	Mekong	Storage, Water supply	Hydrologic change	Dam Future Alternatives
Arias, ME, TA Cochrane, M Kummu, H Lauri, GW Holtgrieve, J Koponen, T Piman. 2014. Impacts of hydropower and climate change on drivers of ecological productivity of Southeast Asia's most important wetland. *Ecological modelling* 272: 252–263.	LMB	Regulated flow	Sediment, Habitat, Primary production	Dam Future Alternatives
Arias, ME, TA Cochrane, T Piman, M Kummu, BS Caruso, TJ Killeen. 2012. Quantifying changes in flooding and habitats in the Tonle Sap Lake (Cambodia) caused by water infrastructure development and climate change in the Mekong Basin. *Journal of Environmental Management* 112: 53–66.	LMB	Regulated flow	Habitat	Dam Future Alternatives
Baird, I. and Mean, M. (2005) 'Sesan river fisheries monitoring in Ratanakiri province, northeast Cambodia: Before and after the construction of the Yali Falls dam in the Central Highlands of Viet Nam'. Bang Lung (Cambodia). 3S Rivers Protection Network and Global Association for People and the Environment.	3S	HP	Fish production, Fish diversity, Non-fish biota, Habitat,	Water regulation
Barbarossa, V, RJP Schmitt, MAJ Huijbregts, C Zarfl, H King, AM Schipper. 2020. Impacts of current and future large dams on the geographic range connectivity of freshwater fish worldwide. *Proceedings of the National Academy of Sciences* 117(7): 3648–3655.	Mekong	Spatial configuration	Connectivity	Dam Future Alternatives

Cochrane, TA, ME Arias, RL Teasley, T Killeen. 2010. Simulated changes in water flows of the Mekong River from potential dam development and operations on the Se San and Sre Pok tributaries. University of Canterbury. Civil and Natural Resources Engineering.	3S	HP, Storage	Hydrologic change	Dam Future Alternatives
Cochrane, TA, ME Arias, T Piman. 2014. Historical impact of water infrastructure on water levels of the Mekong River and the Tonle Sap system, *Hydrology and Earth System Sciences* 18(11): 4529–4541.	Mekong	Storage	Hydrologic change	Water regulation
Golden, CD, A Shapero, B Vaitla, MR Smith, SS Myers, E Stebbins, JA Gephart. 2019. Impacts of Hydropower Development on Fisheries and Human Nutrition in the Lower Mekong, *Frontiers in Sustainable Food Systems* 3(93).	LMB	HP	Fish production	Dam Future Alternatives
Grill, G, C Ouellet Dallaire, E Fluet Chouinard, N Sindorf, B Lehner. 2014. Development of new indicators to evaluate river fragmentation and flow regulation at large scales: A case study for the Mekong River Basin, *Ecological Indicators* 45: 148–159.	Mekong	Spatial configuration	Hydrologic change, Connectivity	Number of dams – strategic assessment
Grimsditch, M. 2012. 3S rivers under threat: Understanding new threats and challenges from hydropower development to biodiversity and community rights in the 3S River Basin. 3S Rivers Protection Network.	3S	HP, Storage, Cost	Fish Diversity, Habitat	None (summary)
Halls, AS and M Kshatriya. 2009. Modelling the cumulative effects of mainstream hydropower dams on migratory fish populations in the lower Mekong basin, Final report to the Mekong River Commission Secretariat.	LMB	Spatial configuration	Fish diversity, Connectivity	Fish passage
International Centre for Environmental Management. 2010. Strategic Environmental Assessment of hydropower on the Mekong Mainstream: Summary of the Final Report. Hanoi, Vietnam. Available online: http://www.mrcmekong.org/assets/Publications/Consultations/SEA-Hydropower/SEA-FR-summary-13oct.pdf.	LMB	HP	Hydrologic change, Sediment, Fish production, Fish diversity, Wetlands, Habitat, Nutrients, Primary production	None (summary)

Intralawan, A, D Wood, R Frankel, R Costanza, I Kubiszewski. 2018. Tradeoff analysis between electricity generation and ecosystem services in the Lower Mekong Basin, *Ecosystem Services* 30: 27–35.	LMB	HP, Cost	Sediment, Nutrients, Fish production, Wetlands, Habitat	Dam Future Alternatives
Kondolf, GM, ZK Rubin, JT Minear. 2014. Dams on the Mekong: Cumulative sediment starvation, *Water Resources Research* 50(6): 5158–5169.	Mekong	Regulated flow	Sediment	Dam Future Alternatives
Kubiszewski, I, R Costanza, P Paquet, S Halimi. 2013. Hydropower development in the lower Mekong basin: alternative approaches to deal with uncertainty, *Regional Environmental Change* 13(1): 3–15.	LMB	HP	Fish production, Wetlands	Dam Future Alternatives
Kummu, M, XX Lu, JJ Wang, O Varis. 2010. Basin-wide sediment trapping efficiency of emerging reservoirs along the Mekong, *Geomorphology* 119(3–4): 181–197.	Mekong	Storage, Regulated flow	Sediment	Dam Future Alternatives
Lauri, H, H de Moel, PJ Ward, TA Rasanen, M Keskinen, M Kummu. 2012. Future changes in Mekong River hydrology: impact of climate change and reservoir operation on discharge, *Hydrology and Earth System Sciences* 9(5): 6569–6614.	LMB	Regulated flow	Hydrologic change	Dam Future Alternatives
Mekong River Commission. 2011. Basin Development Plan Programme, Phase 2: Assessment of Basin-wide Development Scenarios', Mekong River Commission, pp. 1–254.	Mekong	HP, Storage, Cost	Hydrologic change, Fish production, Wetlands, Habitat, Nutrients	Dam Future Alternatives
Ngo, LA, I Masih, Y Jiang, W Douven. 2018. Impact of reservoir operation and climate change on the hydrological regime of the Sesan and Srepok Rivers in the Lower Mekong Basin, *Climatic Change* 149(1): 107–119.	3S	HP	Hydrologic change	SDO
Ngor, PB, P Legendre, T Oberdorff, S Lek. 2018. Flow alterations by dams shaped fish assemblage dynamics in the complex Mekong-3S river system, *Ecological Indicators* 88: 103–114.	LMB	Regulated Flow	Fish Diversity	Water regulation

Natural Heritage Institute. 2017. Sambor Hydropower Dam Alternatives Assessment Final Report. San Francisco, CA. Available online: https://n-h-i.org/wp-content/uploads/2018/03/Volume-1_Executive-Summary.pdf.	LMB	HP	Sediment, Fish production	SDO
Ogonda, K. 2014. Starving the Mekong: Expected social and environmental impacts from construction and operation of the Lower Sesan II Dam. Berkeley, CA. International Rivers.	LMB	HP, Storage, Cost	Hydrologic change, Sediment, Fish production, Fish diversity	None (summary)
Orr, S, J Pittock, A Chapagain, D Dumaresq. 2012. Dams on the Mekong River: Lost fish protein and the implications for land and water resources, *Global Environmental Change* 22(4): 925–932.	Mekong	Spatial Configuration	Hydrologic change, Fish production	Dam Future Alternatives
Ou, C, KO Winemiller. 2016. Seasonal hydrology shifts production sources supporting fishes in rivers of the Lower Mekong Basin, *Canadian Journal of Fisheries and Aquatic Sciences* 73(9): 1342–1362.	LMB	Regulated flow	Fish diversity, Primary production	Water regulation
Piman, T. et al. (2013) 'Assessment of flow changes from hydropower development and operations in Sekong, Sesan, and Srepok rivers of the Mekong basin', Journal of Water Resources Planning and Management. American Society of Civil Engineers, 139(6), pp. 723–732.	3S	HP, Storage	Hydrologic change	Dam Future Alternatives, SDO
Piman, T, TA Cochrane, ME Arias. 2016. Effect of proposed large dams on water flows and hydropower production in the Sekong, Sesan and Srepok rivers of the Mekong Basin, *River Research and Applications* 32(10): 2095–2108.	3S	HP, Storage	Hydrologic change	Number of dams – strategic assessment
Piman, T, T Lennaerts, P Southalack. 2013. Assessment of hydrological changes in the lower Mekong Basin from Basin-Wide development scenarios, *Hydrological Processes* 27(15): 2115–2125.	LMB	Regulated flow	Hydrologic change, Habitat	Dam Future Alternatives
Pokhrel, Y, S Shin, Z Lin, D Yamazaki, J Qi. 2018. A review of the integrated effects of changing climate, land use, and dams on Mekong river hydrology, *Water* 10(3): 266.	LMB	Regulated flow	Hydrologic change, Habitat	Water regulation

Räsänen, TA, OM Joffre, P Someth, CT Thanh, M Keskinen, M Kummu. 2015. Model-based assessment of water, food, and energy trade-offs in a cascade of multipurpose reservoirs: Case study of the Sesan Tributary of the Mekong River, *Journal of Water Resources Planning and Management* 141(1): 5014007.	3S	HP, Storage, Water Supply	Hydrologic change	SDO
Räsänen, TA, O Varis, L Scherer, M Kummu. 2018. Greenhouse gas emissions of hydropower in the Mekong River Basin, *Environmental Research Letters* 13(3): 34030.	Mekong	HP	GHG	Number of dams – strategic assessment
Ringler, C, X Cai. 2006. Valuing fisheries and wetlands using integrated economic-hydrologic modeling—Mekong River Basin, Journal of Water Resources Planning and Management 132(6): 480–487.	Mekong	HP, Water supply	Fish production, Wetlands	Water allocation
Ringler, C, J von Braun, MW Rosegrant. 2004. Water policy analysis for the Mekong River Basin, *Water International* 29(1): 30–42.	Mekong	HP, Water supply	Hydrologic change, Fish production, Wetlands	Dam Future Alternatives
Sabo, JL, A Ruhi, GW Holtgrieve, V Elliott, ME Arias, PB Ngor, TA Rasanen, S Nam. 2017. Designing river flows to improve food security futures in the Lower Mekong Basin, Science 358(6368): eaao1053	LMB	Regulated Flow	Fish Production	SDO
Schmitt, RJP, S Bizzi, A Castelletti, GM Kondolf. 2018. Improved trade-offs of hydropower and sand connectivity by strategic dam planning in the Mekong, Nature Sustainability 1(2018): 96-104.	3S	HP	Sediment	Number of dams – strategic assessment
Schmitt, RJP, S Bizzi, A Castelletti, JJ Opperman, GM Kondolf. 2019. Planning dam portfolios for low sediment trapping shows limits for sustainable hydropower in the Mekong, Science Advances 5(10): 2175.	Mekong	HP	Sediment	Number of dams – strategic assessment

Shaad, K, NJ Souter, T Farrell, D Vollmer, HM Regan. 2018. Evaluating the sensitivity of dendritic connectivity to fish pass efficiency for the Sesan, Srepok and Sekong tributaries of the Lower Mekong, *Ecological indicators* 91: 570–574.	3S	Spatial Configuration	Connectivity	Dam Future Alternatives
Souter, NJ, K Shaad, D Vollmer, HM Regan, TA Farrell, M Arnaiz, PJ Meynell, TA Cochrane, ME Arias, T Piman, SJ Andelman. 2020. Using the Freshwater Health Index to Assess Hydropower Development Scenarios in the Sesan, Srepok and Sekong River Basin, Water 12(3): 788.	3S	Spatial configuration	Hydrologic change, Sediment, Connectivity, Habitat	Dam Future Alternatives
Tran VT, K Sunada, Y Ichikawa. 2011. A spatial impact assessment of human-induced intervention on hydrological regimes: a case study in the upper Srepok River basin, Central Highlands of Vietnam, International Journal of River Basin Management 9(2): 103-116.	3S	HP, Storage	Hydrologic change	Dam Future Alternatives
Trung, LD, NA Duc, LT Nguyen, TH Thai, A Khan, K Rautenstrauch, C Schmidt. 2020. Assessing cumulative impacts of the proposed Lower Mekong Basin hydropower cascade on the Mekong River floodplains and Delta–Overview of integrated modeling methods and results, *Journal of Hydrology* 581: 122511.	LMB	Regulated flow	Hydrologic change, Sediment, Connectivity, Nutrients	Dam Future Alternatives
Wild, TB, DP Loucks. 2014. Managing flow, sediment, and hydropower regimes in the Sre Pok, Se San, and Se Kong Rivers of the Mekong basin, *Water Resources Research* 50(6): 5141–5157.	3S	HP, Storage	Hydrologic change, Sediment	Dam Future Alternatives
Wild, TB, DP Loucks, GW Annandale, P Kaini. 2016. Maintaining sediment flows through hydropower dams in the Mekong River Basin, *Journal of Water Resources Planning and Management* 142(1): 5015004.	3S	HP, Storage	Hydrologic change, Sediment	SDO
Wild, TB, PM Reed, DP Loucks, M Mallen-Cooper, ED Jensen. 2019. Balancing hydropower development and ecological impacts in the Mekong: Tradeoffs for sambor mega dam, *Journal of Water Resources Planning and Management* 145(2): 5018019.	LMB	HP	Hydrologic change, Sediment, Fish production	SDO

Yang, J, YCE Yang, J Chang, J Zhang, J Yao. 2019. Impact of dam development and climate change on hydroecological conditions and natural hazard risk in the Mekong River Basin, *Journal of Hydrology* 579: 124177.	Mekong	Storage	Hydrologic change	Dam Future Alternatives
Yu, W, Y Kim, D Lee, G Lee. 2019. Hydrological assessment of basin development scenarios: Impacts on the Tonle Sap Lake in Cambodia, *Quaternary International* 503: 115–127.	LMB	Regulated flow	Hydrologic change, Habitat	Dam Future Alternatives
Ziv, G, E Baran, S Nam, I Rodriguez-Iturbe, SA Levin. 2012. Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin, *Proceedings of the National Academy of Science* 109(15): 5609–5614.	LMB	HP	Fish Production, Fish Diversity, Habitat	Number of dams – strategic assessment