

Supplementary materials

Tables

Table S1. River function indicators used to develop the science-based questionnaire presented in this paper (indicators and table taken and modified from Parish et al., 2019; Pracheil et al., 2019 and McManamay et al., 2020).

Category	ID	Name	Description
<p>Biota and Biodiversity (BB): Shifts in aquatic, riparian and terrestrial populations and communities have been linked to several aspects of hydropower construction and operation and impacts to aquatic and terrestrial habitats. Accurate assessments of population and community are required to assess the health of the ecosystem.</p>	F1	Abundance, density	Count or other measures of organisms per area
	F51	Algae/ primary productivity (BB)	Measures for algal populations and communities forming basal food web resources
	F5	Behavior, movement, colonization, extinction	Behavior of organisms in study area, including colonization, movement patterns, distance, duration, timing, frequency and/or extinction
	F6	Demographics, age, sex, size	Population demographics, including age, sex, and size
	F7	Fitness, survival, growth, condition, reproduction, mortality	Fitness, survival, growth, condition, reproduction, or mortality of organisms
	F8	Functional group, or species or trait composition	Grouping of organisms by functional or trait status, percentage composition
	F9	Genetics, mixing, meta-population	Genetics and population mixing, including meta-population dynamics
	F10	Habitat, critical habitat, or surrogates of such	Indices of organism habitat, including habitat area, suitability, etc.
	F11	Internal composition nutrient abnormalities	Nutritional composition and makeup of organisms, including elemental stoichiometry; includes levels of internal homeostasis, as well as morphological, genetic, or hormonal abnormalities caused by contaminants
	F2	Life history trait characteristics	Life history trait characteristics and their values, such as duration of spawning, fecundity, reproductive mode (characteristics themselves and not the composition of the community)
	F3	Presence, absence, occupancy, or detection	Organism presence/absence in an area (including pseudo-absence), occupancy, and detection probability
<p>Water Quality (WQ): Water quality characteristics can be directly</p>	F4	Species diversity	Species richness, diversity, evenness, or indices-of-biotic-integrity metrics used to characterize one or more components of the biotic community
	F40	Algae/ primary productivity (WQ)	Algal concentration including measures of primary productivity such as chlorophyll A or cyanotoxin

or indirectly affected by hydro-power development and operation. Changes in water quality can adversely affect the health of humans and wildlife	F41	Buffering capacity	Characteristics including pH, alkalinity
	F42	Dissolved gasses	Concentration of non-greenhouse gases in water
	F43	Dissolved oxygen	Dissolved oxygen in water
	F44	Ecosystem function	Ecosystem vital rates and processes, including gross primary productivity, respiration, biochemical oxygen demand
	F45	Gas emissions	Concentration and ebullition of water-origin greenhouse gases
	F46	Key elements	Elements and compounds that are not listed on the EPA Toxic and Priority Pollutants list
	F47	Macro-molecular pollutants	Pollutants listed on the EPA Toxic and Priority Pollutants list that are not included in other EMH categories
	F48	Nutrients and organic material (C, N, P)	Dissolved organic carbon and other organic non-pollutants essential to life, including nitrogen, phosphorous, and inorganic carbon
	F49	Solid transport, turbidity, and conductivity	Descriptions of dissolved and suspended solids in water such as turbidity, suspended or dissolved solids, conductance
	F50	Water temperature	Water temperature
Geomorphology (GM): Hydro-power development can disrupt a river system's geomorphologic equilibrium through altered sediment and flow regimes, which influence the availability and quality of habitat for plants and animals within the system	F15	Catchment and basin attributes	Upland soil characteristics, topography, and landscape erodibility metrics that could influence soil erosion and wasting related and subsequent sedimentation related to hydropower development
	F16	Channel	Channel properties such as bankfull width, wetted width, bankfull discharge, channel slope, braided channel, channelization
	F17	Floodplain valley	Metrics related to channel confinement, entrenchment, migration, etc.
	F18	Sediment and substrate	Sediment and substrate properties such as substrate particle size, bedload, sediment entrainment or deposition, bedrock composition
Connectivity and Fragmentation (CF): Dams and reservoirs disrupt aquatic, riparian, and terrestrial connectivity, all of which can directly affect the habitat quantity and quality for organisms in an ecosystem	F12	Basin area	Some aspect of area of river basin
	F13	Dendritic network and riverscape	Fragment length, dendritic connectivity index, barrier index, river distance between dams and projects
	F14	Fish passage	Mitigated fish passage, including presence of upstream or downstream passage or length of bypass
	F52	Spillage & turbine entrainment	Entrainment in the spillage & turbine environment such as fish, sediments
Water Quantity (HD): Hydro-power development can alter the hydrologic cycle by impounding free-flowing water, increased evaporation, and altered groundwater recharge. Because dam operations may serve many purposes, temporal changes to water	F24	Basin attributes	Attributes related to factors that influence hydrology (or were used in the context of hydrology), such as climate and precipitation
	F25	Diversion	Quantitative properties of diversions such as volume or discharge of diversion or water for other uses
	F26-31	Downstream discharge	Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics

quantity affect human and wild-life populations through altered water availability

F26	Downstream discharge duration	Downstream discharge duration, where duration is the period associated with a specific flow condition (Poff et al., 1997)
F27	Downstream discharge frequency	Downstream discharge frequency, where frequency refers to how often a flow above a given magnitude recurs over some specified time interval (Poff et al., 1997)
F28	Downstream discharge magnitude	Downstream discharge magnitude, where magnitude is equivalent to the amount of water moving past a fixed location per unit time (Poff et al., 1997)
F29	Downstream discharge periodicity	Downstream discharge periodicity, meaning the order of occurrence of events of a certain magnitude (e.g., did the ten largest floods over a 100-year period all take place in the first 10 years?); flow periodicity affects sediment erosion and deposition as well as the life history completeness of aquatic species; periodicity results from complex interactions of local climate, basin topography, land use patterns, riverbed morphology, and other factors (Yang et al., 2014)
F30	Downstream discharge rate-of-change	Downstream discharge rate-of-change, i.e., flashiness, refers to how quickly flow changes (Poff et al., 1997)
F31	Downstream discharge timing	Downstream discharge timing, where timing refers to the regularity (i.e., predictability) with which flow of a defined magnitude occurs (Poff et al., 1997)
F32	Groundwater	Groundwater characteristics
F33-39	Upstream hydrology	Reservoir hydrological characteristics such as residence time, reservoir fluctuation, reservoir surface area, or degree of regulation; Measures describing the magnitude, frequency, duration, periodicity, and timing of flows upstream of a hydro-power facility, including changes to these characteristics
F33	Reservoir hydrology	Reservoir hydrological characteristics such as residence time, reservoir fluctuation, reservoir surface area, or degree of regulation
F34	Upstream inflow duration	Upstream inflow duration, where duration is the period of time associated with a specific flow condition (Poff et al., 1997)
F35	Upstream inflow frequency	Upstream inflow frequency, where frequency refers to how often a flow above a given magnitude recurs over some specified time interval (Poff et al., 1997)
F36	Upstream inflow magnitude	Upstream inflow magnitude, where magnitude is equivalent to the amount of water moving past a fixed location per unit time (Poff et al., 1997)
F37	Upstream inflow periodicity	Upstream inflow periodicity, meaning the order of occurrence of events of a certain magnitude (e.g., did the ten largest floods over a 100-year period all take place in the first 10 years?); flow periodicity affects sediment erosion and deposition as well as the life history completeness of aquatic species; periodicity results from complex interactions of local climate, basin

			topography, land use patterns, riverbed morphology, and other factors (Yang et al., 2014)
	F38	Upstream inflow rate-of-change	Upstream inflow rate-of-change, i.e., flashiness, refers to how quickly flow changes (Poff et al., 1997)
	F39	Upstream inflow timing	Upstream inflow timing, where timing refers to the regularity (i.e., predictability) with which flow of a defined magnitude occurs (Poff et al., 1997)
Land Cover (LC): Land cover influences many other environmental properties ranging from river and floodplain sedimentation rates to fragmentation of habitats and wildlife populations. Land cover changes can include increases in wetted surface from reservoir formation, and fragmentation of the surrounding landscape by infrastructure (e.g., transmission lines, roads).	F19	Area impacted, project area	Project boundary area, area impacted by the project as whole, not related to reservoir inundation or land cover
	F20	Floodplain or riparian vegetation	Properties of floodplain or riparian vegetation such as riparian encroachment or floodplain area
	F21	Land cover class	Type of land cover, changes in land cover
	F22	Protected land	Spatial properties of protected lands including losses or increases
	F23	Reservoir inundation	Reservoir area, upland or floodplain inundation, biomass inundated/lost

Table S2. Science-based questions (SBQ) provided to evaluate potential effects of dams on river functions.(questions modified from Parish et al., 2019; Pracheil et al., 2019 and McManamay et al., 2020).

Question_ID	Question	Project Type	Area	Biota	Taxa	Key Q	Reference
Q_1	Are bare banks of the reservoir apparent and prone to erosion?	EHA + NPD	Reservoir	N	Not	No	Hale & Bayne 1982
Q_2	Are certain fluvial specialists requiring distinct flow regimes missing from the downstream river community?	EHA + NPD	Downstream	Y	Not	No	Anderson et al. 2006; Mims & Olden 2013; McManamay & Frimpong 2015; McManamay et al. 2013; Travnicek & Maceina 1994; Freeman et al. 2001; Balcombe et al. 2011; Perkin & Bonner 2011; García et al. 2011; Humphries et al. 1999
Q_3	Are aquatic communities dominated by one or a few species (relative to expected richness)?	EHA + NPD	Downstream	Y	Taxa-Specific	No	Taylor et al. 2014; Quinn & Kwak 2003; Suttikus & Mettee 2009; Mortenson & Weisberg 2010; Olden et al. 2006
Q_4	Are aquatic species that require certain turbidity levels missing from the downstream river community or rare?	EHA + NPD	Downstream	Y	Taxa-Specific	No	Hoagstrom et al. 2008; Worthington et al. ; Wildhaber et al. 2000
Q_5	Are floodplain vegetation communities dominated by	EHA + NPD	Downstream	N	Taxa-Specific	No	Braatne et al. 2007; Catford et al. 2011; DeWine et al. 2007; Mortenson et al.

	invasives or generalist plant species?						2010; Stromberg et al.2007; Thomas 1996; Townsend 2001
Q_6	Are floodplain vegetation communities missing flood-dependent species?	EHA + NPD	Down-stream	N	Taxa-Specific	No	Braatne et al. 2007; Catford et al. 2011; DeWine et al. 2007; Mortenson et al. 2010; Stromberg et al.2007; Thomas 1996; Townsend 2001
Q_7	Are flows over the spillway flowing into a large or deep plunge pool?	All	Project	N	Not	No	
Q_8	Are invasive species found in project lands or waters?	All	Basin	Y	Taxa-Specific	No	Havel et al. 2005; Olden et al. 2006; Johnson et al. 2008; Mortenson & Weisberg 2010
Q_9	Are large amounts of sediment accumulating at river tributary junctions with reservoir?	EHA + NPD	Reservoir	N	Not	No	Haregeweyn et al. 2006; Baade et al. 2012
Q_10	Are natural barriers to fish migration absent downstream of project?	All	Basin	N	Not	Yes	
Q_11	Are particular methods well suited for collecting a given focal species while other methods are maladapted for species detection?	All	Basin	Y	Taxa-Specific	No	McManamay et al. 2014; Murchie et al. 2008
Q_12	Are portions of the historically active floodplain currently inactive (i.e., not inundated at any point during most years)?	EHA + NPD	Down-stream	N	Not	No	Pearsal et al. 2005; Karim et al. 2015
Q_13	Are sensitive species or focal species life histories, reproductive behaviors, and habitat requirements poorly known?	All	Basin	Y	Taxa-Specific	No	Vaughn & Taylor 2000
Q_14	Are sensitive species or species expected to be common rare in surveys?	All	Basin	Y	Taxa-Specific	No	Wildhaber et al. 2000; Kupferberg et al. 2012
Q_15	Are surficial stream bed grain sizes appear very coarse or devoid of sand and gravel substrates compared to neighboring streams of similar geology and gradient?	EHA + NPD	Down-stream	N	Not	No	Kondolf et al. 1997; Brandt 2000; Graf 2006; McManamy et al. 2010; Grant 2012; Kobayashi et al. 2008

Q_16	Does the project have facilities located in close proximity up or downstream (ie., part of a cascade)?	All	Basin	N	Not	No	FERC 2015; McManamay et al. 2016; Grill et al. 2015; Nicols et al. 2006; Ouyang et al. 2010; Zhai et al. 2010; Li et al. 2012
Q_17	Are there eutrophication or algal blooms in close proximity (immediately upstream or downstream) or in reservoir of the project?	All	Basin	N	Not	No	Wang et al. 2012; Chen et al. 2011; Carneiro et al, 2014
Q_18	Are there excessive heavy metals in close proximity (immediately upstream or downstream) or in reservoir of the project?	All	Basin	N	Not	No	Carneiro et al, 2014
Q_19	Are there activities or land-cover in the ustream basin that could influence hydrology and operations at the facility?	All	Basin	N	Not	No	Stickler et al. 2013; Knoll et al. 2003; Smedberg et al. 2009
Q_20	Are certain fish and invertebrate (or other) functional groups or regionally representative species missing from the project lands or waters that would be expected in this system?	EHA + NPD	Project	Y	Taxa-Specific	No	Liermann et al. 2012; Oliveira et al. 2017; Taylor et al. 2014; Quinn & Kwak 2003; Suttkus & Mettee 2009; Mims & Olden 2013; Olden et al. 2006
Q_21	Are there complex life histories of organisms that display significant movement or complex behaviors for feeding, reproduction, or refugia?	All	Basin	Y	Taxa-Specific	No	
Q_22	Is there evidence of elevated nutrient loads to project waters?	All	Basin	N	Not	No	Knoll et al. 2003; Smedberg et al. 2009; Jones et al. 2004
Q_23	Are there IUCN-listed species, China Red Data Book of Endangered Animals-listed species, or species of concern found in or adjacent to project lands or waters?	All	Basin	Y	Taxa-Specific	No	Jelks et al. 2008; Ziv et al. 2012; Grumbine and Pandit 2013; Pandit and Grumbine 2012; Wildhaber et al. 2000; Kupferberg et al. 2012; Chen, et al, 1998; IUCN Red list of threatened.
Q_24	Are there factors upstream or downstream that may compete with project operations, such as reservoirs, water control structures, diversions, canals, intakes/discharges, or irrigation?	All	Basin	N	Not	No	FERC 2015; Kanno & Vokoun 2010; Freeman Marcinek 2006; Gibbins et al. 2001; McManamay et al. 2014; Poff and Hart 2002; Gibbins et al. 2001; Hanasaki et al. 2006; Gordon et al. 2005

Q_25	Are there fish consumption advisories in the reservoir, downstream river, region or watershed?	All	Basin	N	Not	No	Cunningham et al. 1994; EPA 2011
Q_26	Are there juveniles of an endangered species that may move downstream through turbines?	All	Project	Y	Taxa-Specific	No	Coutant and Whitney 2000; Brown et al. 2012
Q_27	Are there migratory species or species that require riverine dispersal to complete life history requirements located in proximity to the project?	All	Basin	Y	Taxa-Specific	No	Perkin and Gido 2012; Perkin et al. 2014; Vaughn & Taylor 2000; Dudley & Platania 2007
Q_28	Are there notable changes in fish and invertebrate community, loss of richness or important indicator groups compared to surrounding streams?	EHA + NPD	Downstream	Y	Taxa-Specific	No	Pozo et al. 1997
Q_29	Are there reports of fish kills in project waters?	EHA + NPD	Project	N	Not	No	
Q_30	Are there reports of hazardous water pollution accidents in project waters?	EHA + NPD	Project	N	Not	No	
Q_31	Are there terrestrial IUCN-listed species, China Red Data Book of Engangered Animals-listed species, species of concern, or critical habitats found in or adjacent to project lands or waters?	All	Basin	Y	Taxa-Specific	No	Grumbine and Pandit 2013; Pandit and Grumbine 2012; Chen, et al, 1998; IUCN Red list of threatened.
Q_32	Are there water quality issues in the project waters related to upstream or adjacent land use near reservoirs?	All	Basin	N	Not	No	Knoll et al. 2003; Smedberg et al. 2009; Jones et al. 2004
Q_33	Are upland areas within or adjacent to project boundaries characterized by steep terrain (at least 20% slope)?	All	Basin	N	Not	No	Elliot & Hall 1997; Laflen et al. 1997; Stickler et al. 2013
Q_34	Could abundance or density values of focal species provide insights into habitat needs, suitability, or limited habitats?	All	Basin	Y	Taxa-Specific	No	Wildhaber et al. 2000; Kupferberg et al. 2012
Q_35	Do any of the project reservoirs have a Degree of Regulation $\geq 4\%$ (DOR is the %	All	Project	N	Not	No	Nilsson et al. 2005; Lehner et al. 2011

	of annual flow potentially stored by a dam)						
Q_36	Do any of the sensitive species or species of concern constitute a representative sub-population (or nested population) of a greater meta-population?	All	Basin	Y	Taxa-Specific	No	Fullerton et al. 2011; Weigel et al. 2013
Q_37	Do any fish have external lesions, curved spines, malformations?	EHA + NPD	Project	Y	Not	Yes	Schleiger 2004; Adams 1990; Adams et al. 1993; Van den Avyle et al. 1989
Q_38	Do any fish have hemorrhaging or bloating of stomach, odd swimming behavior, presence of bubbles under thin dermal layers?	EHA + NPD	Downstream	Y	Not	Yes	
Q_39	Do habitat conditions below the dam consist of a dry stream or stagnant pools with little flowing water?	EHA + NPD	Downstream	N	Not	No	McManamay et al. 2015
Q_40	Do hydrologic statistics (e.g., Indicators of Hydrologic Alteration) show at least 20% + or - changes from inflows?	EHA + NPD	Downstream	N	Not	No	Richter et al. 2012; Richter et al. 1996, 1998; Poff et al. 2010; Sakaris 2013
Q_41	Do migratory aquatic species occur downstream of the facility, but not upstream of the facility?	EHA + NPD	Basin	Y	Taxa-Specific	No	Catalano et al. 2007; Kiffney et al. 2008; Benstead et al. 1999; Hall et al. 2011; Young et al. 2012; Harford & McLaughlin 2007; Jager et al. 2015
Q_42	Do nearest downstream facilities have a fish passage facility?	All	Basin	N	Not	No	McKay et al. 2013; Schram et al. 2016; DeRolph et al. 2016; Young et al. 2012
Q_43	Do noxious, invasive, or hyperabundant algal blooms or mats (e.g., Didymo) occur in the downstream river of the project?	EHA + NPD	Downstream	N	Not	Yes	Cooke 1980; Thomson et al. 2005; Flinders & Hart 2009
Q_44	Do noxious, invasive, or hyperabundant algal blooms or mats (e.g., Didymo) occur in the reservoir?	EHA + NPD	Reservoir	N	Not	No	Cooke 1980; Thomson et al. 2005; Flinders & Hart 2009
Q_45	Do point and lateral bars show signs of inactive maintenance (i.e., covered in vegetation, little influence of deposition and erosion by flows)?	EHA + NPD	Downstream	N	Not	No	Trush et al. 2000; Draught et al. 2011

Q_46	Do project operations divert flow through a bypass system around native stream channel?	All	Project	N	Not	Yes	Baker et al. 2010; McManamay et al. 2013
Q_47	Do species tend to show movement or colonization in response to changes in flows?	EHA + NPD	Downstream	Y	Taxa-Specific	No	Bunt et al. 1999; Butler et al. 2011; David & Closs 2002; Decker et al. 2008
Q_48	Do surveys suggest that specific age cohorts, size groups, or life stages are missing from occurrences of rare or of-concern species?	EHA + NPD	Project	Y	Taxa-Specific	No	Gillette et al. 2005
Q_49	Do upland areas within or adjacent to project boundaries contain highly erosive soils or lack vegetation? (e.g., Erosive soils typically have Rainfall Erosivity Factors > or = 5)	All	Basin	N	Not	No	Elliot & Hall 1997; Laflen et al. 1997; Stickler et al. 2013; EPA 2017
Q_50	Does "dry dock" occur at any time during the year?	EHA + NPD	Reservoir	N	Not	No	Jaakson 1973; Gabriel 2004
Q_51	Does any part of the project waters receive effluent from mine tailings or has mining occurred proximate to the project?	All	Basin	N	Not	No	
Q_52	Does aquatic community richness seem unnaturally low?	EHA + NPD	Downstream	Y	Not	No	Taylor et al. 2014; Quinn & Kwak 2003; Suttkus & Mettee 2009; Mortenson & Weisberg 2010; Olden et al. 2006; Anderson et al. 2006; Freeman Marcinek 2006
Q_53	Does evidence suggest that overall ecosystem productivity is limiting healthy fish and invertebrate communities?	EHA + NPD	Downstream	Y	Not	No	
Q_54	Does habitat seem homogeneous or lacking in major components (e.g., varied depths, velocities, velocity shelters, etc)?	EHA + NPD	Downstream	Y	Not	No	Orth 1987; Leonard and Orth 1988; Bo-vee 1998
Q_55	Does or has the project operate a fish passage facility or will the project have plans to include a fish passage facility?	All	Project	Y	Not	Yes	Schram et al. 2016; DeRolph et al. 2016; Young et al. 2012

Q_56	Does pH in project waters seem very high (>8) or very low (<6) relative to ambient conditions upstream of project?	All	Project	N	Not	Yes	USGS 2016
Q_57	Does signs of scouring during high-flow seasons or high-flow activity appear limited?	EHA + NPD	Downstream	N	Not	No	Trush et al. 2000; Draught et al. 2011
Q_58	Does the channel appear excessively miniturized?	EHA + NPD	Downstream	N	Not	No	Nilsson et al. 2000; Takahashi & Nakamura 2011; McManamay et al. 2013
Q_59	Does the dam and reservoir prevent the majority of bed-load from upstream sources from reaching reaches below dam?	All	Downstream	N	Not	Yes	Kondolf et al. 1997; Graf 2006; Grant 2012; Csiki & Rhoads 2014
Q_60	Does the downstream river (or streams in the region) have "losing" reaches or strong alternating patterns of "losing" and "gaining" systems?	All	Downstream	N	Not	No	Stanford et al. 1994; Benenati et al. 1998; Stromberg et al. 2007; Bond et al. 2010
Q_61	Does the downstream river support predominantly coldwater fishes or a tailwater trout fishery?	EHA + NPD	Downstream	Y	Not	No	Krause et al. 2005; Almodóvar & Nicola 1999; McKinney et al. 2011; Nelson 1986; Sabaton et al. 2008
Q_62	Does the project alter seasonal hydrology or reduce flood magnitude from inflows?	All	Project	N	Not	No	Cushman et al. 1985; McManamay et al. 2016; Fitzhugh & Vogel 2011; Gao et al. 2009; Pozo et al. 1997
Q_63	Do project operations fall in any category besides run-of-river?	All	Project	N	Not	No	Cushman et al. 1985; McManamay et al. 2016; Fitzhugh & Vogel 2011; Gao et al. 2009; Pozo et al. 1997
Q_64	Does the project boundary border or occur adjacent to protected lands (i.e., those managed for wildlife, recreation, conservation, or special purposes by federal/state/local governments, or NGOs, or conservation easements)?	All	Project	N	Not	Yes	Hynes & Hanley 2006; Zhao et al. 2010, 2013; Richardson et al. 2000
Q_65	Does the project have a non-integral type dam-powerhouse development, including but not limited to diversion-bypass?	All	Project	N	Not	No	McManamay et al. 2016; Coutos and Olden 2018;
Q_66	Does the project have extensive land assets (more than	All	Project	N	Not	No	Falcone et al. 2010

	just acreage around dam, powerplant, and switchyard)?						
Q_67	Does the project have multiple developments?	All	Project	N	Not	No	McManamay et al. 2016
Q_68	Does the project have one reservoir larger than > 6000 Megaliters?	All	Project	N	Not	No	Falcone et al. 2010
Q_69	Does the project have plans to sell lands to an entity or manage lands for conservation purposes?	All	Project	N	Not	Yes	
Q_70	Does the project changes any downstream monthly flows larger than 20%?	EHA + NPD	Project	N	Not	No	Poff et al. 2007; Moyle and Mount 2007;
Q_71	Does the project induce pressure-related trauma to fish (e.g., fish with bulging eyes or ruptured swim bladders in tailrace)?	EHA	Project	Y	Taxa-Specific	Yes	Coutant and Whitney 2000; Brown et al. 2012
Q_72	Does the project occur downstream or adjacent to current or historic industrialization?	All	Basin	N	Not	No	Smedberg et al. 2009
Q_73	Does the project occur in karst terrain or terrian with complex groundwater interactions?	All	Basin	N	Not	No	Benenati et al. 1998
Q_74	Does the project occur in region overlying an aquifer with known water shortage issues?	All	Basin	N	Not	No	Stanford et al. 1994; Perkin et al. 2014; Braatne et al. 2007
Q_75	Does the project operate in a peaking mode or intermediate peaking mode?	All	Project	N	Not	No	Wehmeyer & Wagner 2011
Q_76	Does the project serve as flood control, or long-term storage?	All	Project	N	Not	No	Cushman et al. 1985; McManamay et al. 2016; Scruton et al. 2003; Scruton et al. 2008; Bruno et al. 2009; Cereghino & Lavandier 1998; Lauters et al. 1996; Jennings & Freeman 2003; Grabowski & Isely 2007
Q_77	Does the project operate the spillway more than 1/2 of the time?	All	Project	N	Not	Yes	
Q_78	Does the project fragment protected land assets (e.g., affecting migratory patterns or	All	Project	N	Not	Yes	Dwire & Kauffman 2003; Hu et al. 2011; Johnson 1998

	migratory corridors of wildlife or fire regimes)?						
Q_79	Does the reservoir have a average depth less than 15 meters?	All	Reservoir	N	Not	No	Bastviken et al. 2004
Q_80	Does the reservoir have large amounts of organic matter input (leaves, detritus, wood) or were trees left standing prior to reservoir inundation?	All	Reservoir	N	Not	No	Fearnside 1995; Duchemin 1995; Bastviken et al. 2004
Q_81	Does the reservoir have significant sedimentation and filling?	EHA + NPD	Reservoir	N	Not	No	St. Louis et al. 2000
Q_82	Does the reservoir or dam impede land or water-based migratory corridors for terrestrial or aquatic species?	All	Project	Y	Taxa-Specific	No	Hu et al. 2011
Q_83	Does the reservoir or downstream river support a commercial or recreational fishery?	EHA + NPD	Project	Y	Not	No	Loomis et al. 1986; Paller 1997; Rulifson 1990
Q_84	Does the reservoir or lower river harbor significant macrophyte communities?	EHA + NPD	Reservoir	N	Not	No	Sullivan et al. 2013
Q_85	Does the reservoir periodically inundate areas of perennial woody plant growth, potentially creating wetlands?	EHA + NPD	Reservoir	N	Not	No	
Q_86	Were trees removed from the reservoir prior to inundation?	EHA + NPD	Reservoir	N	Not	No	
Q_87	Does the reservoir surface elevation fluctuate more than 10 meters among seasons?	All	Reservoir	N	Not	Yes	Paller 1997; Hale & Bayne 1982; Miranda et al. 1984
Q_88	Does the stream channel appear highly stabilized or highly channelized ?	EHA + NPD	Downstream	N	Not	No	Trush et al. 2000;
Q_89	Has development or operations effected upland areas?	All	Basin	N	Not	No	Li et al. 2012; Thomas 1996; Stickler et al. 2013; Ervin et al. 2006; EPA 2017
Q_90	Has land development surrounding the reservoir (and proximate upstream watershed) experienced significant changes since project development?	EHA + NPD	Reservoir	N	Not	No	Johnson 1998; Zhao et al. 2010, 2013; Ouyang et al. 2009

Q_91	Has past mitigation or in-stream flow proved unsuccessful at improving ecological conditions in project waters?	EHA + NPD	Downstream	N	Not	No	McManamay et al. 2013; Bednarek & Hart 2005
Q_92	Is there evidence of fish injury by spillway passage at the project?	EHA + NPD	Project	Y	Taxa-Specific	No	Heisey et al. 1996
Q_93	Has the project limited dispersal by organisms such that there are evidence of declines in populations or reproduction?	EHA + NPD	Basin	Y	Taxa-Specific	No	Faulks et al. 2011; Fullerton et al. 2011; Weigel et al. 2013; Haponski et al. 2007; Skalski et al. 2008
Q_94	Has the reservoir increased water levels (i.e., decreased depth to groundwater)?	EHA + NPD	Reservoir	N	Not	No	
Q_95	Has the reservoir influenced surrounding community's socioeconomics including influencing adjacent land development?	EHA + NPD	Reservoir	N	Not	No	Teigland 1999; Bohlen & Lewis 2009; Hynes & Hanley 2006; Richardson et al. 2000
Q_96	Have any habitat classification measures been conducted or proposed for the downstream river or project lands (e.g., mesohabitat classification for PHABSIM) that would support a patch-occupancy type approach?	All	Basin	N	Not	No	McManamay et al. 2014; Peoples et al. 2013
Q_97	Have backwaters, wetlands, or oxbows been cut off from expected (i.e., natural or target range) exchange of flows and high-flow activity?	EHA + NPD	Downstream	N	Not	No	Frazier & Page 2006; Light et al. 1998; Humphries et al. 1999; Karim et al. 2015; Humphries et al. 2006
Q_98	Have operations reduced floodplain inundation to be infrequent for this system (less than 50% based on expected or target ranges)?	EHA + NPD	Downstream	N	Not	No	Trush et al. 2000; Nislow et al. 2002; Nilsson et al. 2000; Pearsall et al. 2005; Townsend 2001
Q_99	Have past biological sampling methodologies within the project area been heterogeneous (conducted under a variety of methods)?	All	Basin	Y	Taxa-Specific	No	McManamay et al. 2013; Murchie et al. 2008
Q_100	If the project operates a fish passage facility, does it inefficiently or uneffectively pass	EHA + NPD	Project	Y	Taxa-Specific	No	

	target fish (passage rates < 90%; survival rates < 95%)?						
Q_101	Is "irrigation" or "water supply" listed as a congressionally authorized or state authorized purpose of the dam?	All	Project	N	Not	No	
Q_102	Is DO regularly <5 ppm in any of the project waters?	EHA + NPD	Project	N	Not	Yes	Wehmeyer & Wagner 2011; Water Resource Center 2014
Q_103	Is excess sedimentation and siltation apparent in downstream river compared to neighboring streams of similar geology and gradient?	EHA + NPD	Downstream	N	Not	No	Baker et al. 2010;
Q_104	Is free-flowing river habitat a limiting factor in aquatic or terrestrial organisms completing life history requirements?	EHA + NPD	Basin	Y	Not	No	Perkin and Gido 2012; Perkin et al. 2014; Vaughn & Taylor 2000; Dudley & Platania 2007
Q_105	Is growth, survival, or recruitment of any rare species or species of concern inhibited or limited by project development or operations?	EHA + NPD	Project	Y	Taxa-Specific	No	Lukas & Orth 1995; Rulifson 1990; Kupferberg et al. 2012
Q_106	Is intermittency common for streams in the region or the downstream river?	All	Basin	N	Not	No	Balcombe et al. 2011; Perkin; Bond et al. 2010; Stromberg et al. 2007; Benenati et al. 1998; Bond et al. 2010; Hauer & Lorang 2004
Q_107	Is mean annual flow downstream of a project at least 10% less than mean annual inflow?	EHA + NPD	Downstream	N	Not	No	Anderson et al. 2006; Baker et al. 2010; Poff et al. 2010; Freeman & Marcinek 2006; Poff and Hart 2002; McManamay 2014
Q_108	Is riparian vegetation encroaching the channel? Does the channel appear excessively and uncharacteristically braided?	EHA + NPD	Downstream	N	Not	No	Bohn et al. 2000; Carter Johnson et al. 1995; Nilsson et al. 2000; Takahashi & Nakamura 2011; McManamay et al. 2013; Osterkamp & Hupp (2010)
Q_109	Is invertebrate communities, spawning habitat, and/or recruitment of reservoir sport-fish possibly limited by shoreline habitats and water level fluctuations?	EHA + NPD	Reservoir	Y	Not	No	Miranda et al. 1984
Q_110	Is spawning of focal species (i.e., any species of concern or importance) never observed or does reproduction	EHA + NPD	Project	Y	Taxa-Specific	No	Kupferberg et al. 2012; Peoples et al. 2013

	appear limited by habitat or conditions?						
Q_111	Is species recruitment limited by altered sediment sizes or turbidity below the dam?	EHA + NPD	Downstream	Y	Taxa-Specific	No	Hoagstrom et al. 2008; Worthington et al. ; Wildhaber et al. 2000
Q_112	Is the channel confined by embankments (i.e. roads, levees) or unable to migrate if relevant?	EHA + NPD	Downstream	N	Not	No	Trush et al. 2000; Hall et al. 2000; McManamay et al. 2013
Q_113	Is the channel slope high ($\geq 2\%$) and have low sinuosity (< 1.2) (e.g., high stream power presenting more shear on streambed)?	All	Downstream	N	Not	No	Brandt 2000; McManamay et al. 2013; Grant 2012
Q_114	Is the downstream river missing species expected to occur in the river due to thermal intolerance (e.g., cold-cool water specialists if a cool system, or warm water specialists if a warm system)?	EHA + NPD	Downstream	Y	Not	No	Krause et al. 2005; Olden and Naiman 2010; Mims and Olden 2013
Q_115	Is the ecosystem structure or foodweb structure very complex in the river system (i.e., is food-web modeling needed to understand the system)?	EHA + NPD	Downstream	Y	Not	No	Lauters et al. 1996; Chester & Norris 2006; Pozo et al. 1997
Q_116	Is the project located on a river or stream (not a conduit or canal)?	All	Project	N	Not	No	FERC 2018
Q_117	Is the project the most downstream facility on a river system (i.e., nearest to estuary) or a major tributary?	All	Basin	N	Not	Yes	Nilsson et al. 2005; FERC 2015; Hall et al. 2011; Young et al. 2012; Harford & McLaughlin 2007; Jager et al. 2015
Q_118	Is the project the most upstream facility on a river system or major tributary?	All	Basin	N	Not	No	FERC 2015; McManamay et al. 2016; Grill et al. 2015; Nicols et al. 2006; Ouyang et al. 2010; Zhai et al. 2010; Li et al. 2012
Q_119	Is the reservoir discharge a hypolimnetic or epilimnetic release?	All	Reservoir	N	Not	Yes	Webb and Walling 1997; Krause et al. 2005; Olden and Naiman 2010; McManamay et al. 2013; Preece & Jones 2002
Q_120	Is the reservoir highly productive (i.e., have high photosynthetic activity)?	EHA + NPD	Reservoir	N	Not	No	Pozo et al. 1997; Wang et al. 2015
Q_121	Is the reservoir relatively new (i.e., new or recent development, last 30 years)?	EHA + NPD	Reservoir	N	Not	No	Fearnside 1995; St Louis et al. 2000;

Q_122	Is the reservoir relatively warm during summer months (>35°C) or occur in a tropical location?	All	Reservoir	N	Not	No	Fearnside 1995; St Louis et al. 2000;
Q_123	Is the reservoir thermally stratified during any point in the year?	EHA + NPD	Reservoir	N	Not	No	Olden and Naiman (2010); Pozo et al. 1997; Hart & Sherman 1996
Q_124	Is the river below the dam missing aquatic species with life histories dependent on specific sediment sizes?	EHA + NPD	Down-stream	Y	Taxa-Specific	No	McManamay et al. 2013
Q_125	Is there a need to conduct routine community surveys or monitoring of populations or communities?	All	Project	Y	Taxa-Specific	No	Kupferberg et al. 2012; McManamay et al. 2013; Travnicek & Maceina 1994
Q_126	Does agricultural landcover occupy at least 10% of area in upstream watershed above facility?	All	Basin	N	Not	No	Stickler et al. 2013; Knoll et al. 2003; Jones et al. 2004
Q_127	Are there human activities associated with nutrient loads(e.g, agriculture, aquaculture, urbanization, water treatment) in the watershed upstream of the facility?	All	Basin	N	Not	No	Stickler et al. 2013; Knoll et al. 2003; Smedberg et al. 2009; Jones et al. 2004
Q_128	Is there an adult of an endangered species at risk of turbine passage and injury or mortality by blade strike?	All	Basin	Y	Taxa-Specific	No	Deng et al. 2011; Pracheil et al. 2016
Q_129	Is there evidence of blade-strike injury and/or mortality (e.g., decapitation or amputation, turbine blade-strike scars on fish)?	EHA	Project	Y	Taxa-Specific	Yes	Pracheil et al. 2016
Q_131	Is there evidence of fish impingement against bar or trash racks, louvers, or other turbine screening devices?	EHA	Project	Y	Taxa-Specific	Yes	Noatch and Suski 2012
Q_132	Is there free-flowing river habitat upstream or downstream of the project or between developments within the project?	All	Basin	N	Not	No	Cote et al. 2009; Perkin and Gido 2012; Perkin et al. 2014; Nilsson et al. 2005; Grill et al. 2015; Hall et al. 2011; Jager et al. 2015
Q_133	If upstream industrial, agricultural, or urbanization activities are present, would	All	Basin	N	Not	No	Stickler et al. 2013; Knoll et al. 2003; Jones et al. 2004

	you consider them intense (i.e., >20% landcover)?						
Q_134	Is the fish community unnaturally dominated by generalists (e.g., sunfish, "cosmopolitan" species)	EHA + NPD	Down- stream	Y	Not	No	Anderson et al. 2006; Freeman Marcinek 2006
Q_135	Does urban or developed landcover occupy at least 10% of area in upstream watershed above facility?	All	Basin	N	Not	No	Stickler et al. 2013; Smedberg et al. 2009; Esselman et al. 2011
Q_136	Is upstream sedimentation and land use practices contributing to increased levels of sedimentation in the reservoir?	All	Basin	N	Not	No	Baade et al. 2012
Q_137	Is urbanization and/or suburban development significant in lands surrounding the reservoir?	EHA + NPD	Reservoir	N	Not	No	Zhao et al. 2010, 2013
Q_138	Under baseflow conditions, do parts of the channel remain dry or uninundated, potentially limiting habitat for some guilds?	EHA + NPD	Down- stream	N	Not	No	Tennant 1976; Orth & Maughn 1981; Travnichek & Maceina 1994; Freeman et al. 2001
Q_139	Will habitat-based instream flow criteria (IFIM, PHABSM) likely be used for evaluating alternative flow regimes?	All	Project	Y	Not	No	Bovee 1982; Bovee et al. 1998; Orth 1987; Leonard & Orth 1988; Stalnaker et al. 2017
Q_140	Has or will the project resulted in loss of acreage or impact to protected lands?	All	Project	N	Not	Yes	Ouyang et al. 2009;

Table S3. Environmental-envelop model answers for GZBP and cascade GZBP&TGP.

Question	Answer for GZBP	Answer for GZBP&TGP	Notes
What is the size of the project in megawatts?	2715	25215	GRanD database
What is the mean annual flow (cms) of river being im- pounded?	14300	14300	
How high is the dam in meters?	47	185	
What is the storage of the reservoir(s) in megaliters?	1580000	39300000	
What is the surface area of the reservoir(s) in square kilometers?	53.2	1084	
How many total fish species of conservation concern are located in project area or basin?	2	40	List of key protected wild animals in China (2021)
How many total aquatic species of conservation con- cern are located in project area or basin?	2	2	List of key protected wild animals in China (2021)
How many terrestrial species of conservation concern are located in the project area or basin?	0	40	List of National Key Protected Wild Plants in China (2021)
Will the project impact any habitats critically im- portant for sustaining species at risk of extinction?	Yes	Yes	
Will the project impact lands of conservation value?	Yes	Yes	

Figures



Figure S1 Predictive EEM ranges of new developed GZBP



Figure S2 The proportion of questions answered "yes", "no", or "uncertain" relative to different river functions for new developed GZBP

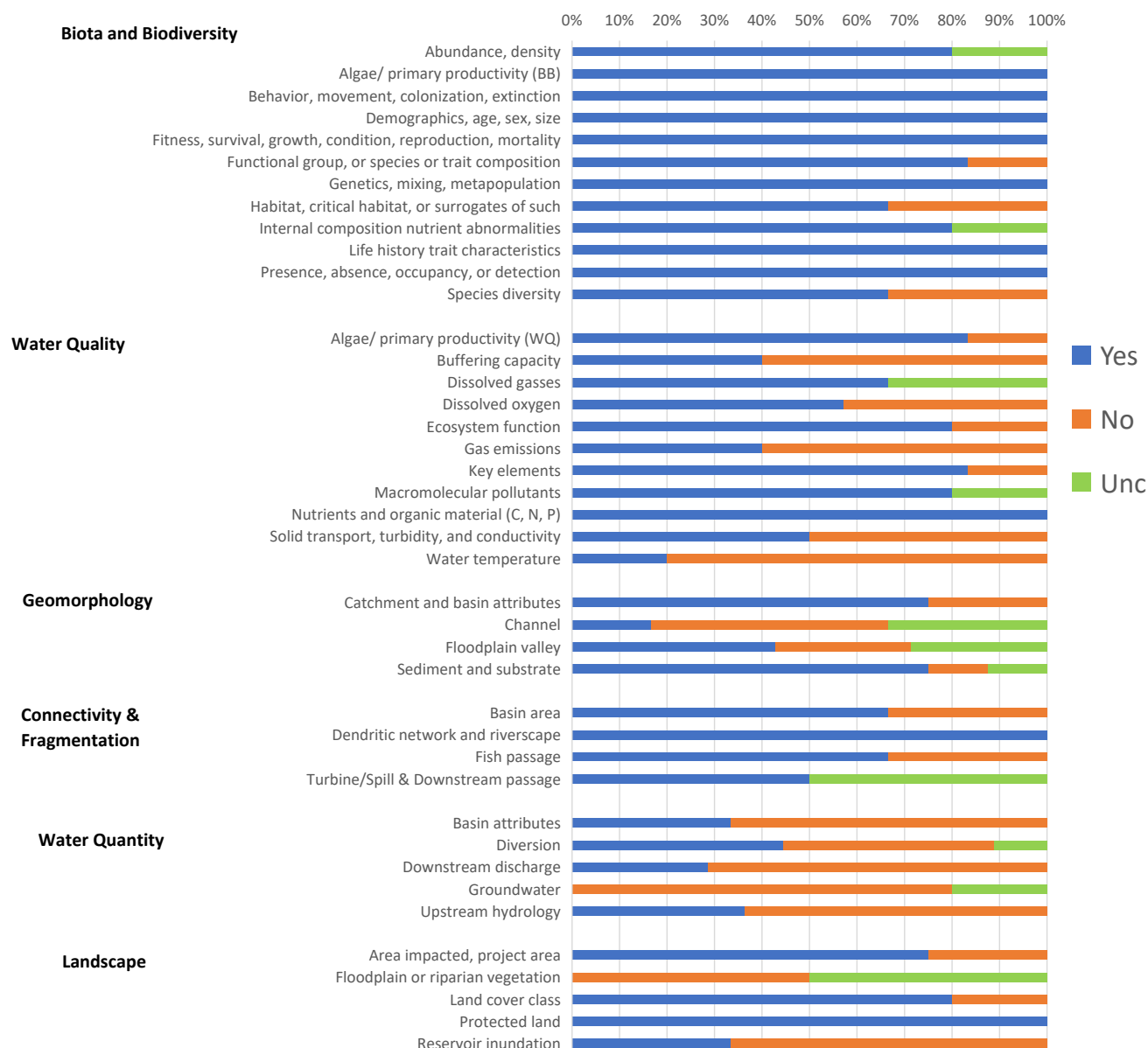


Figure S3 The proportion of questions answered "yes", "no", or "uncertain" relative to different river functions for existing

GZBP

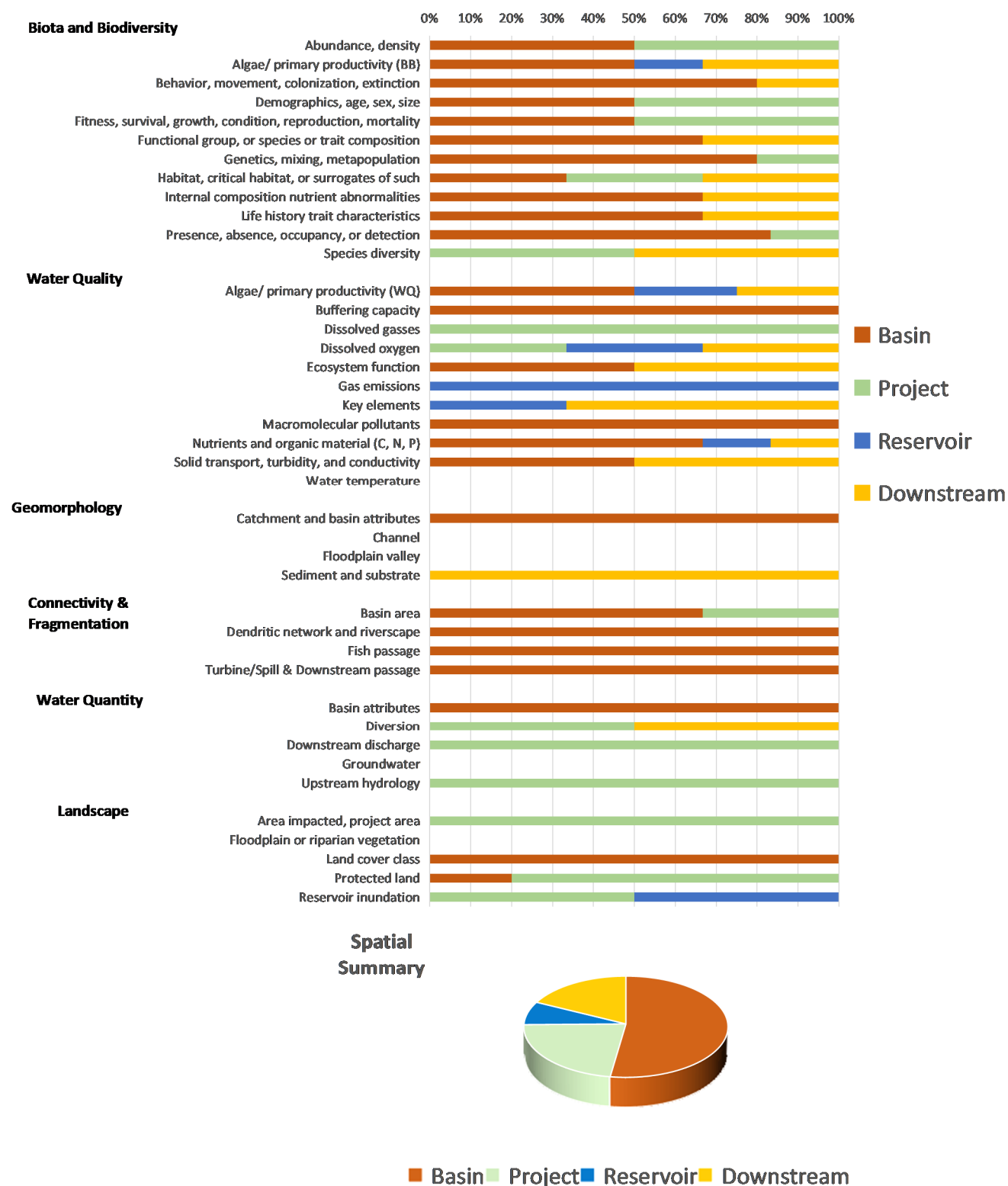


Figure S4 The proportion of questions answered "yes" according to different river functions that are relevant to specific spatial scales for new developed GZBP

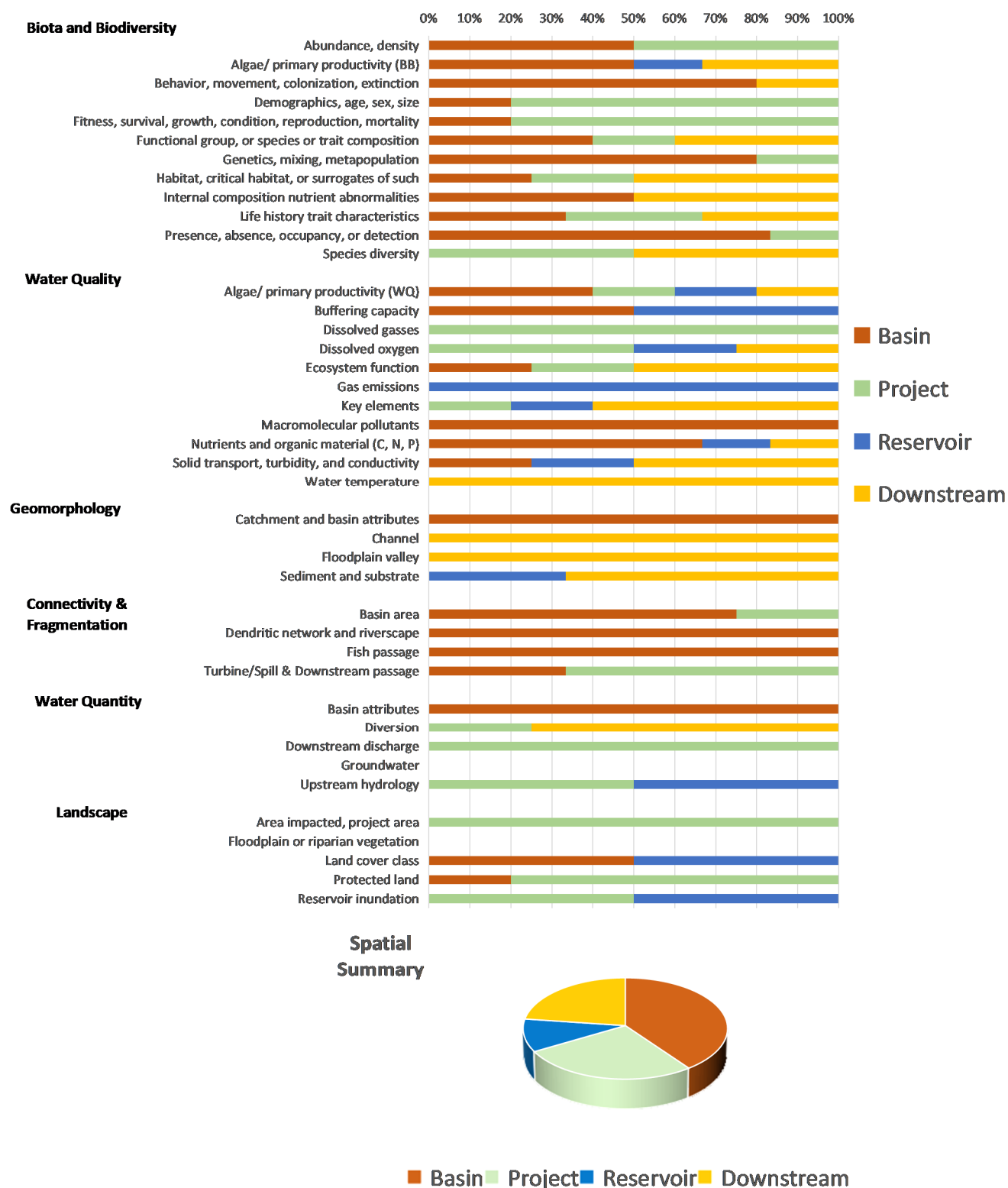


Figure S5 The proportion of questions answered "yes" according to different river functions that are relevant to specific spatial scales for existing GZBP

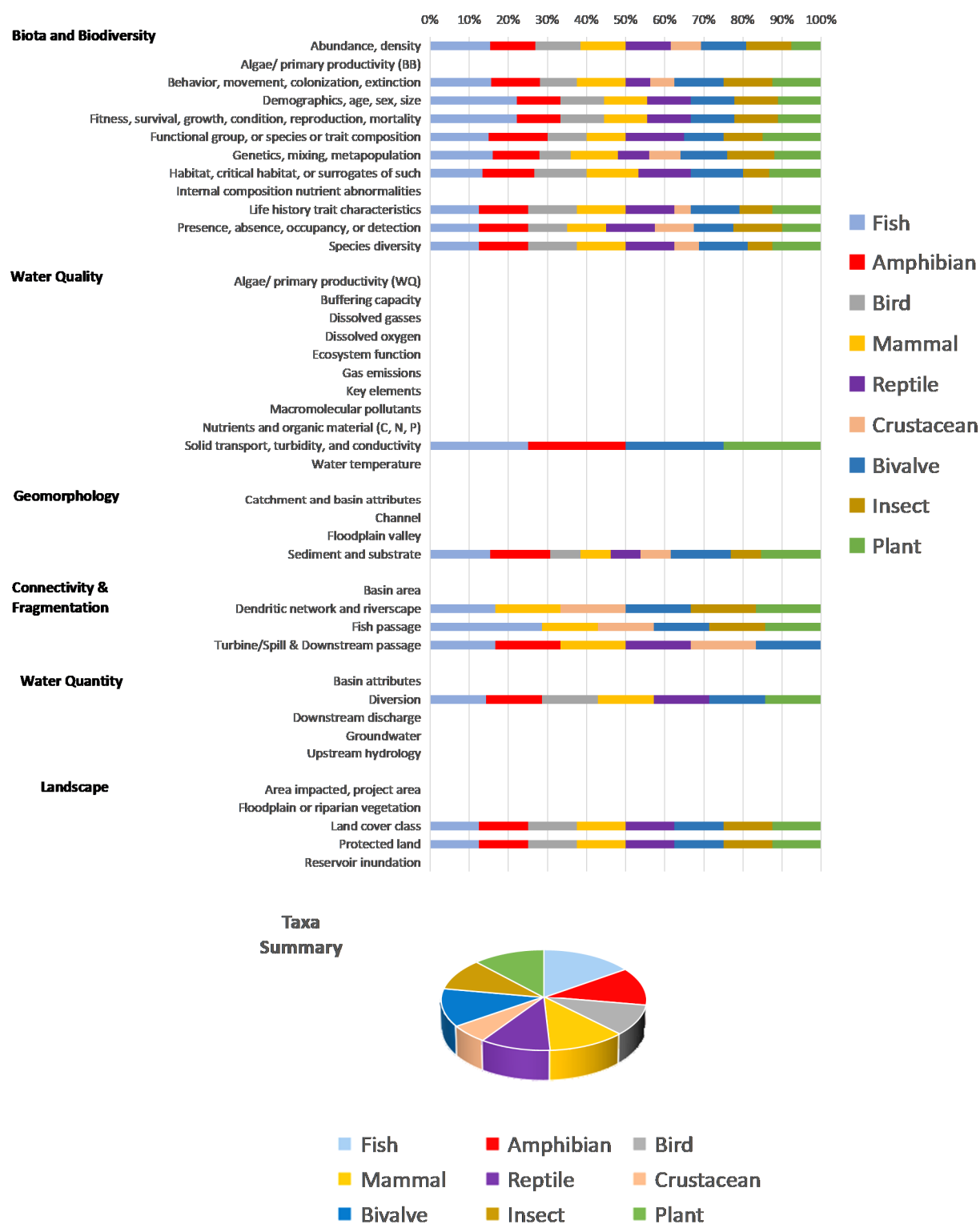


Figure S6 The proportion of questions answered "yes" according to different river functions that are relevant to specific taxonomic groups for new developed GZBP

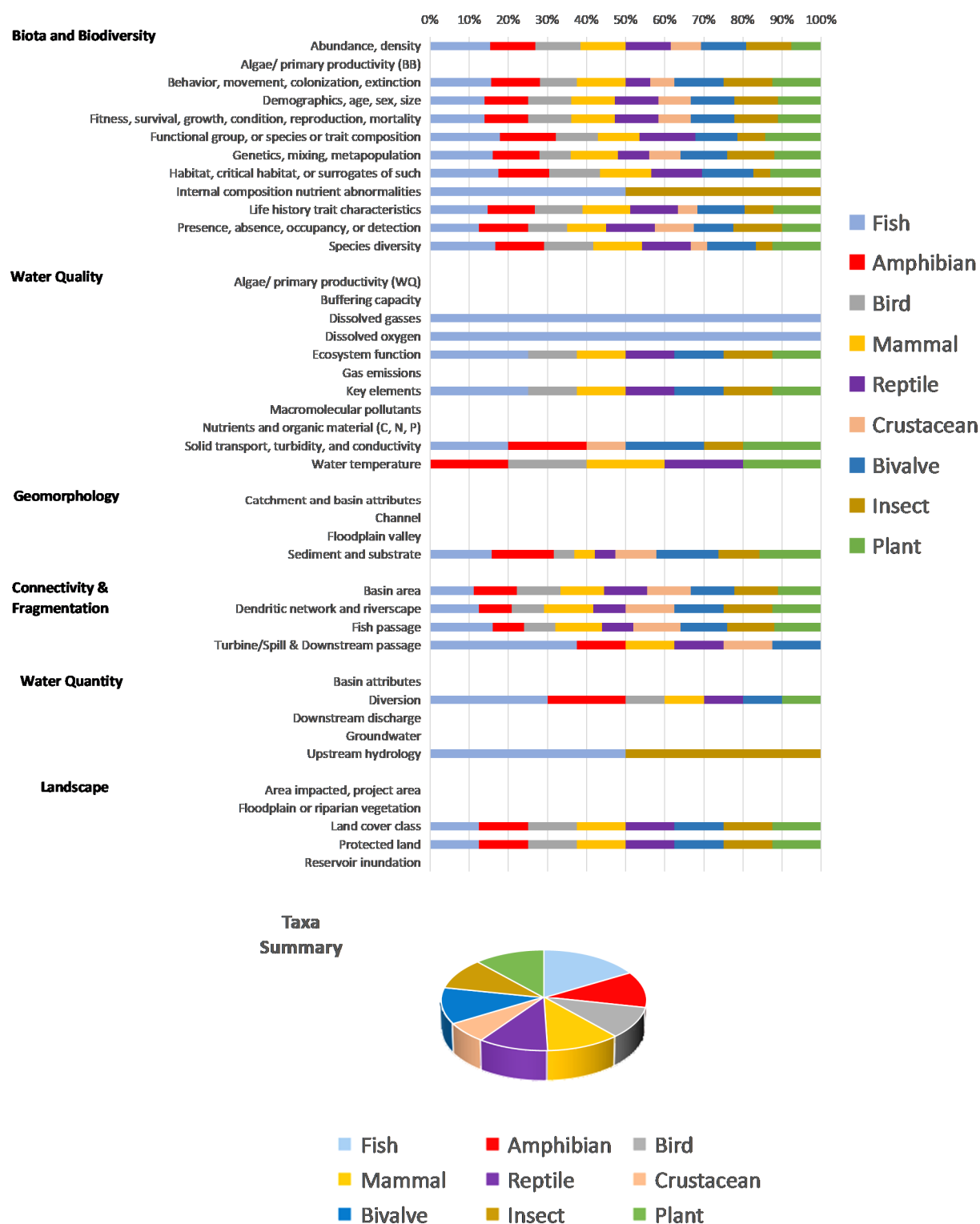


Figure S7 The proportion of questions answered "yes" according to different river functions that are relevant to specific

taxonomic groups for new developed GZBP



Figure S8 Predictive EEM ranges of new developed cascade GZBP&TGP

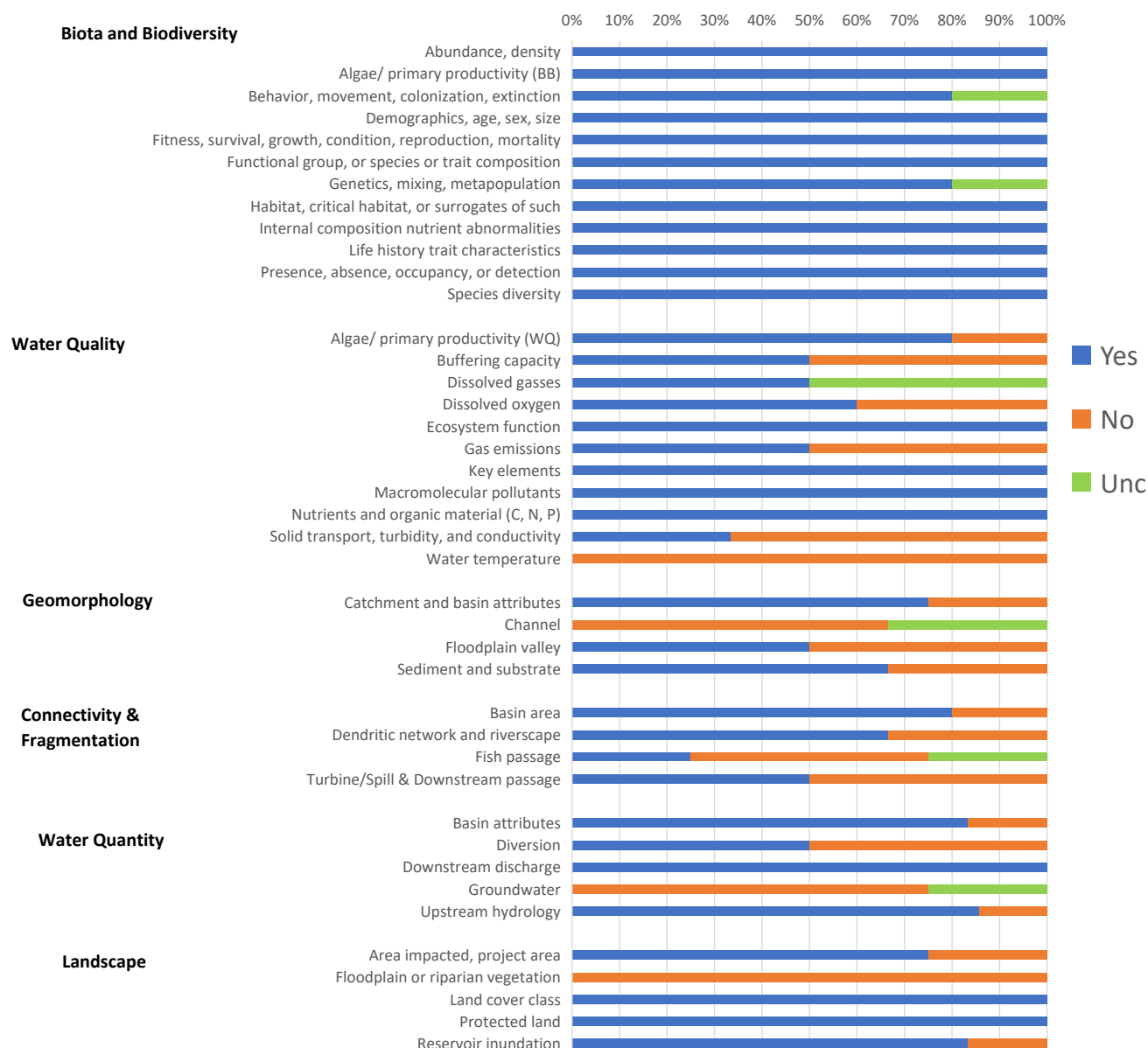


Figure S9 The proportion of questions answered "yes", "no", or "uncertain" relative to different river functions for new developed cascade GZBP&TGP

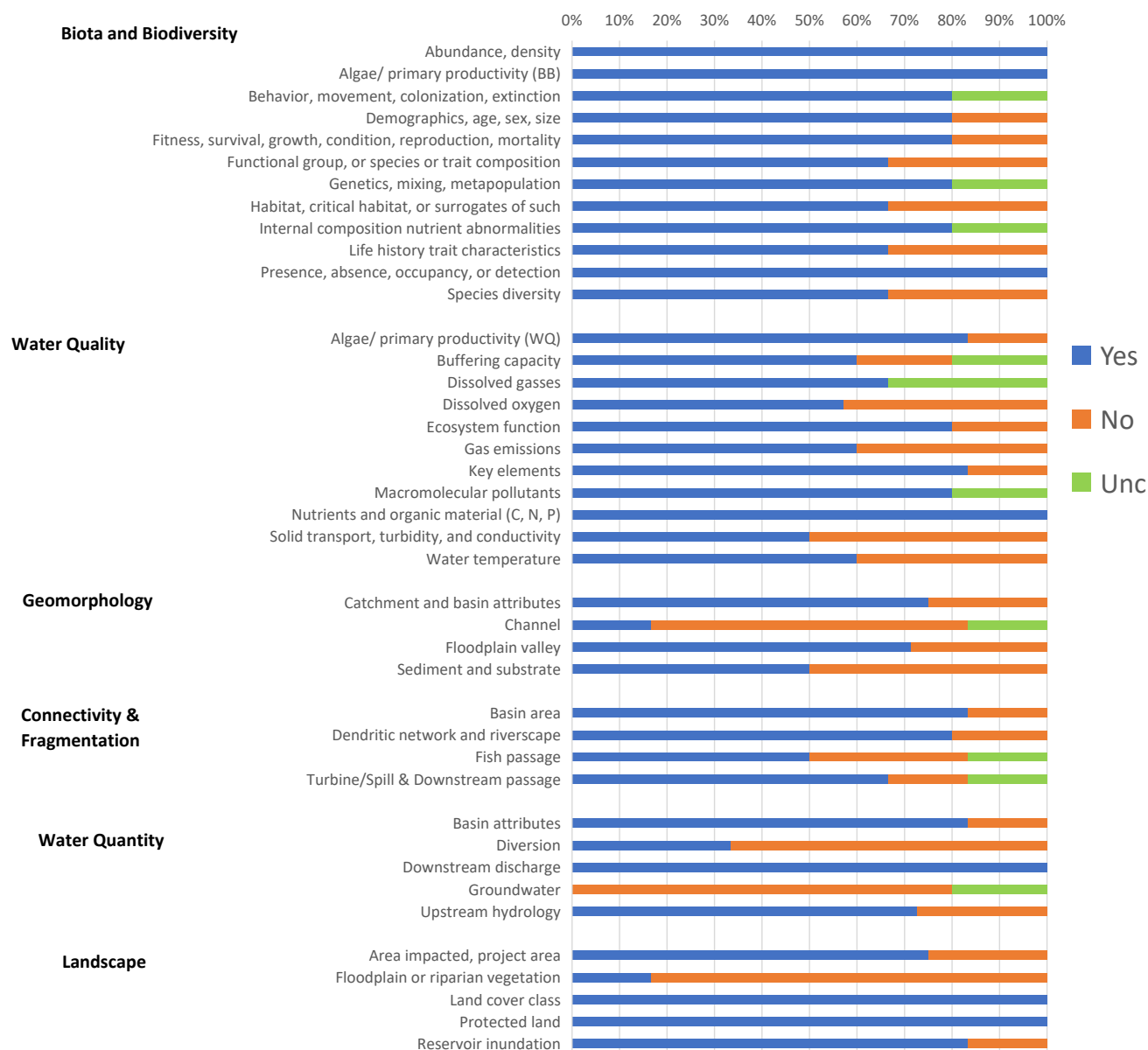


Figure S10 The proportion of questions answered "yes", "no", or "uncertain" relative to different river functions for existing cascade GZBP&TGP

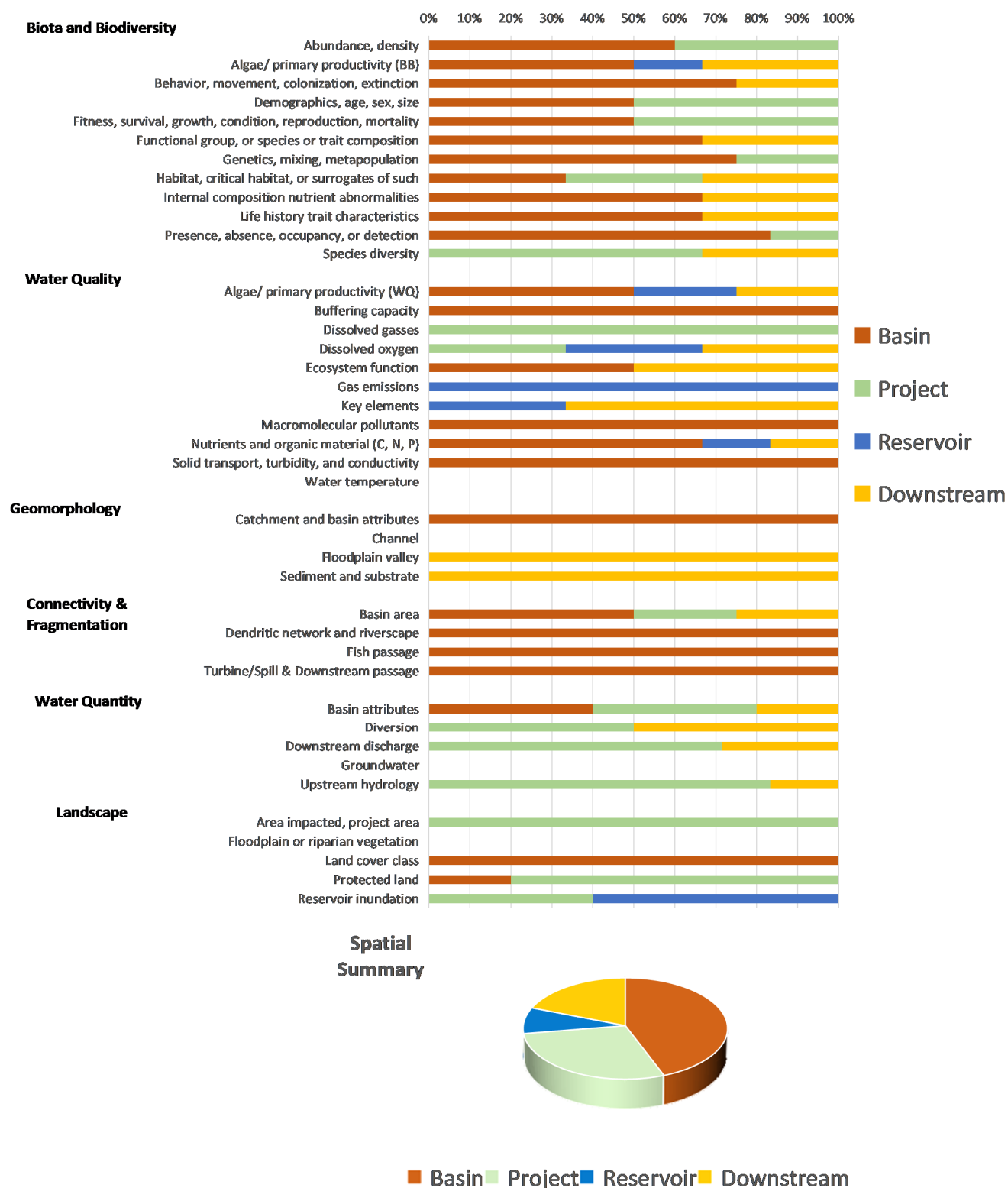


Figure S11 The proportion of questions answered "yes" according to different river functions that are relevant to specific spatial scales for new developed cascade GZBP&TGP

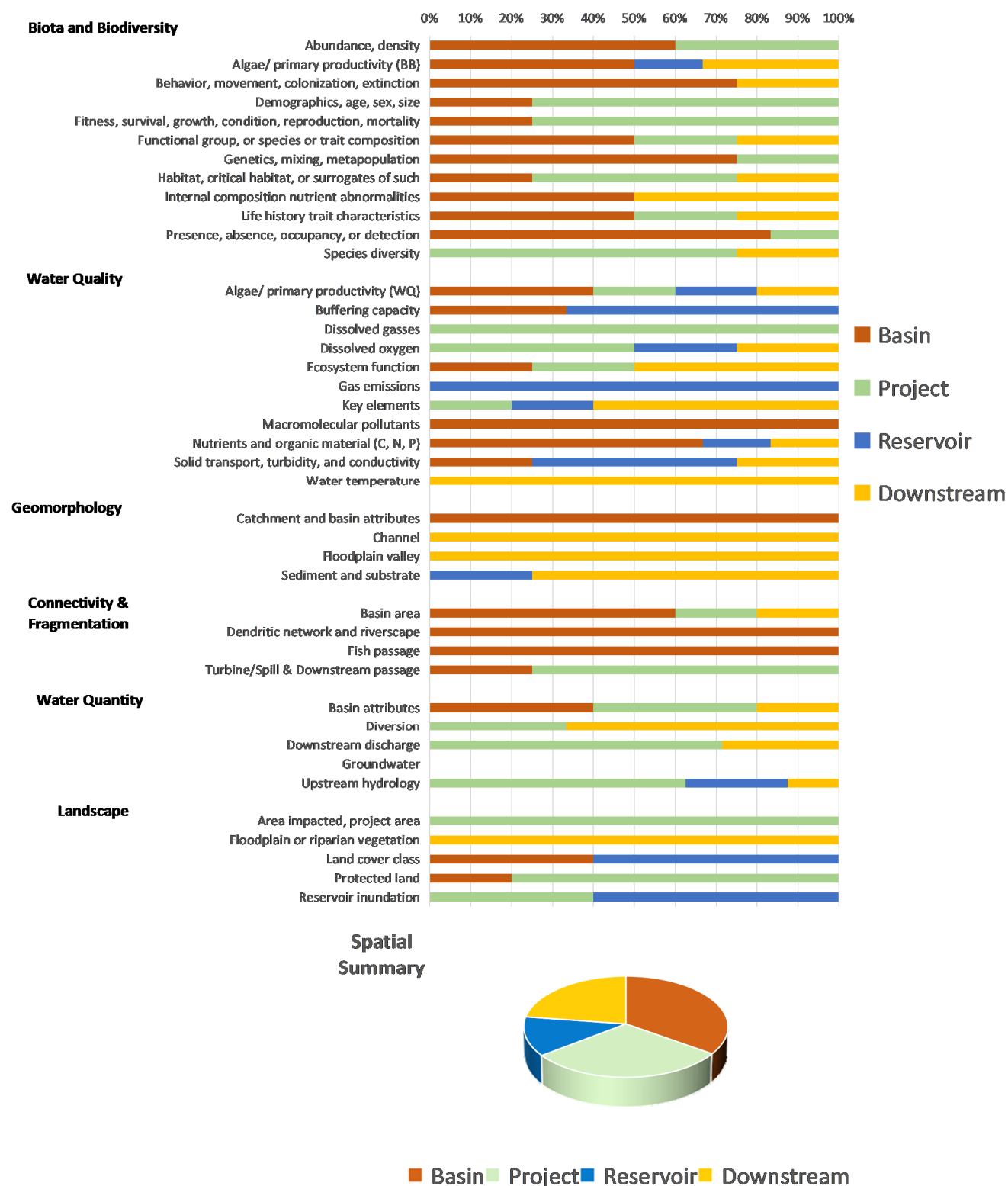


Figure S12 The proportion of questions answered "yes" according to different river functions that are relevant to specific spatial scales for existing cascade GZBP&TGP

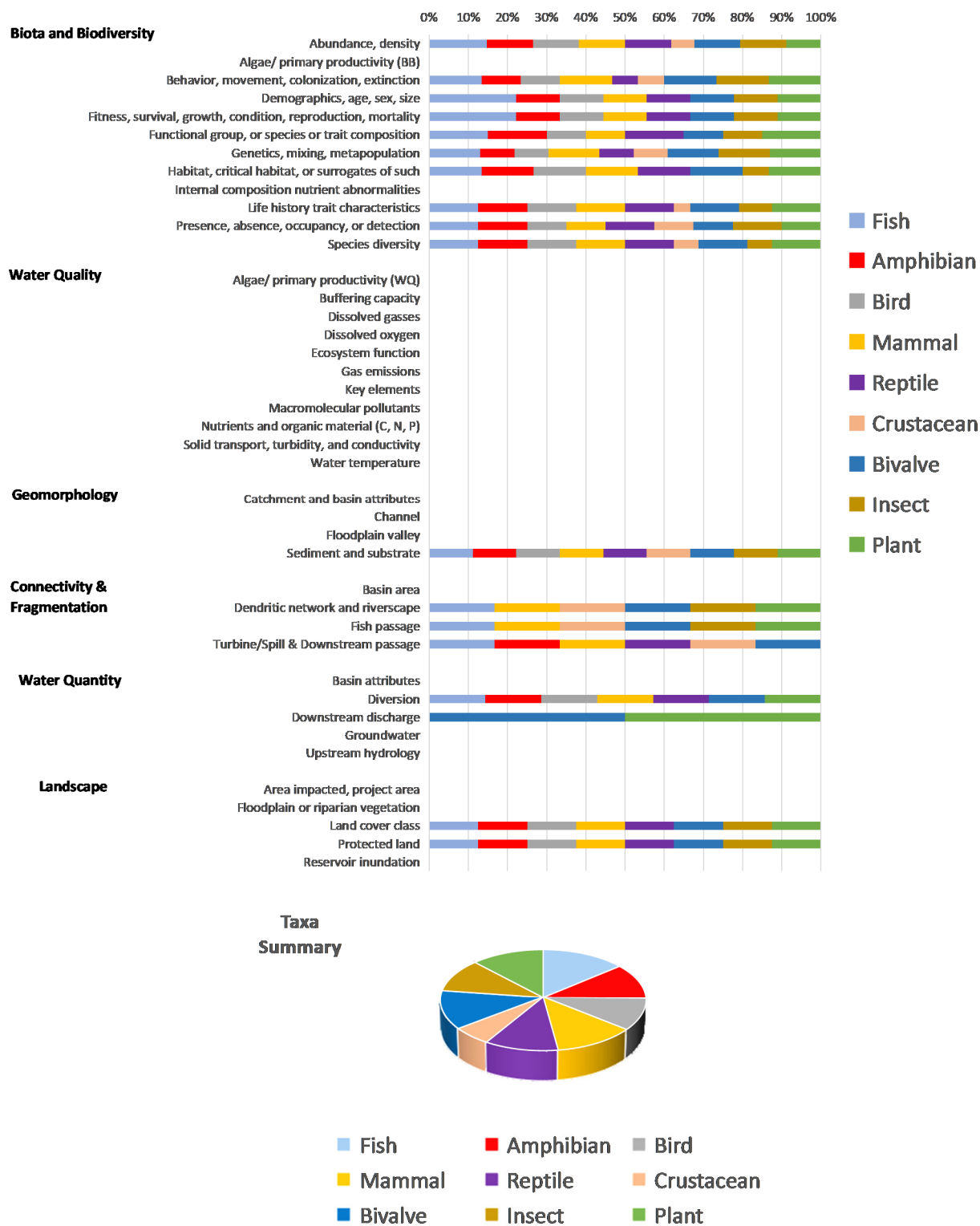


Figure S13 The proportion of questions answered "yes" according to different river functions that are relevant to specific taxonomic groups for new developed cascade GZBP&TGP

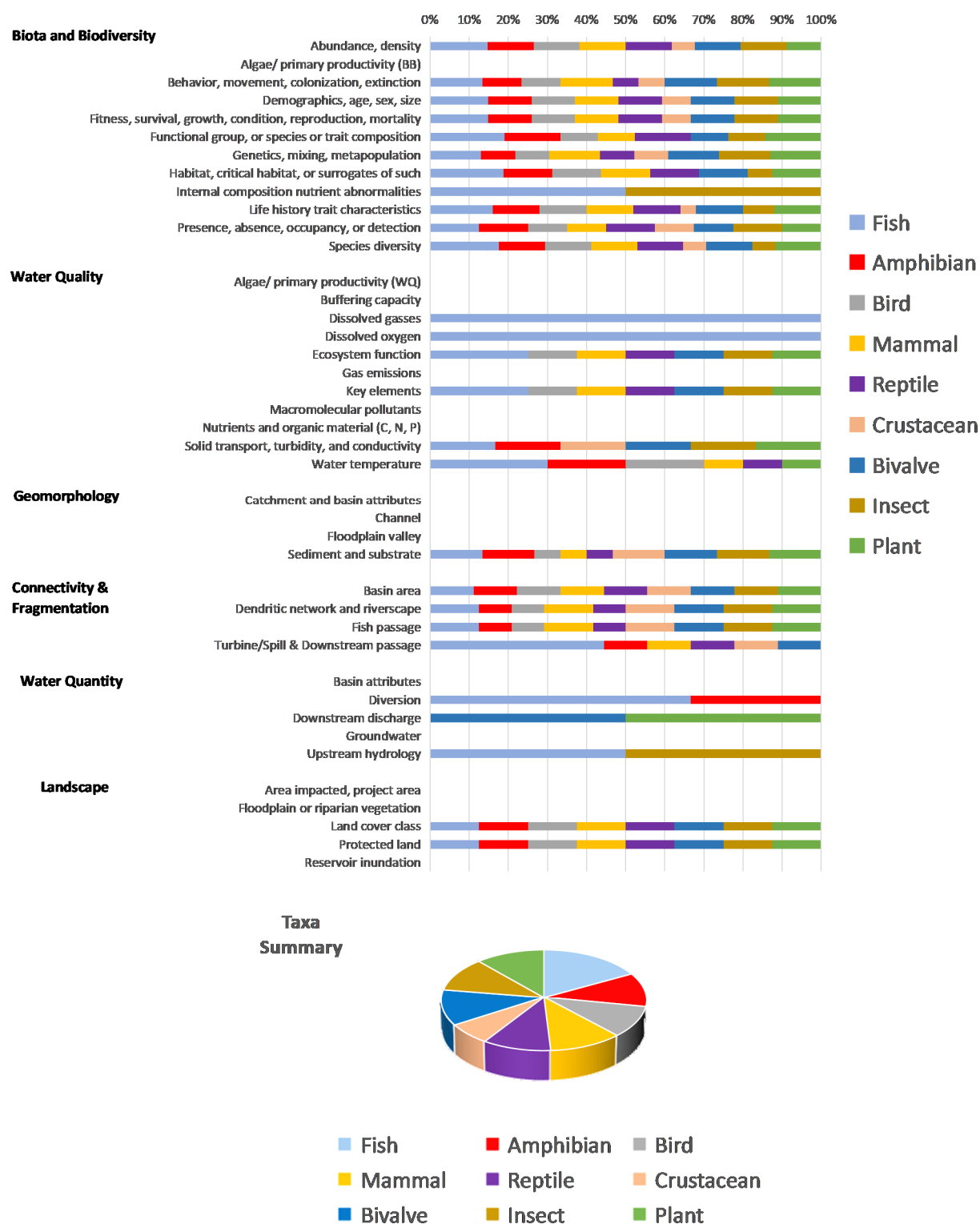


Figure S14 The proportion of questions answered "yes" according to different river functions that are relevant to specific taxonomic groups for new developed cascade GZBP&TGP