DEVELOPMENT AND ENVIRONMENT

Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong

Basin-scale planning is needed to minimize impacts in mega-diverse rivers

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POLICY

The world's most biodiverse river basins—the Amazon, Congo, and Mekong—are experiencing an unprecedented boom in construction of hydropower dams. These projects address important energy needs, but advocates often overestimate economic benefits and underestimate far-reaching effects on biodiversity and critically important fisheries. Powerful new analytical tools and high-resolution environmental data can clarify trade-offs between engineering and environmental goals and can enable governments and funding institutions to compare alternative sites for dam building. Current site-specific assessment protocols largely ignore cumulative impacts on hydrology and ecosystem services as ever more dams are constructed within a watershed (*1*). To achieve true sustainability, assessments of new projects must go beyond local impacts by accounting for synergies with existing dams, as well as land cover changes and likely climatic shifts (*2*, *3*). We call for more sophisticated and holistic hydropower planning, including validation of technologies intended to mitigate environmental impacts. Should anything less be required when tampering with the world's great river ecosystems?

ONE-THIRD OF FRESHWATER FISH AT RISK. The Amazon, Congo, and Mekong basins hold roughly one-third of the world's freshwater fish species, most of which are not found elsewhere. Each of these rivers has experienced limited hydropower development to date, largely because their vast catchments had limited infrastructure and low energy demand. Most existing dams are relatively small and located in upland tributaries, but more than 450 additional dams are planned for these three rivers alone (see the chart), with many already under construction (*4*). Dams are usually built where rapids and waterfalls boost hydropower potential. Unfortunately, these high-gradient reaches are home to many unique fishes adapted for life in fast water (fig. S1).

Although available data on geographic distributions of tropical fishes and other aquatic taxa are incomplete, recent research within these great river basins makes it clear that dam site selection matters greatly for conserving biodiversity (*5*) (see the chart). Given recent escalation of hydropower development in the tropics (*4*), planning is needed at the basin scale to minimize biodiversity loss, as well as other environmental, social, and economic effects (*3*, *6*–*9*). Large dams invariably reduce fish diversity but also block movements that connect populations and enable migratory species to complete their life cycles. This may be particularly devastating to tropical river fisheries, where many high-value species migrate hundreds of kilometers in response to seasonal flood pulses (*8*–*12*). Model simulations of proposed dams in the lower Mekong Basin predict major reductions of migratory stocks (*8*), as has been widely observed globally (*11*). Fish passages constructed to mitigate dam impacts on migratory fishes in the neotropics have proven unsuccessful (*10*) and even harmful (*12*). Yet, dam proposals continue to tout fish passages as the principal means for minimizing impacts on migratory stocks.

"[D]am site selection matters greatly for conserving biodiversity."

Large dams delay and attenuate seasonal flood pulses, reducing fish access to floodplain habitats that are essential nursery areas and feeding grounds. Physical alterations bring about an ecological regime shift, whereby a dynamic system with high structural and functional complexity becomes relatively homogeneous and less productive. Tropical reservoir fisheries are often dominated by low-value species plus a few nonindigenous species introduced for recreational angling or aquaculture (*13*). Ecological effects of large dams are not limited to rivers; trapping sediment alters nutrient dynamics and other biogeochemical processes in deltas, estuaries, and marine-shelf ecosystems, which in turn impact agriculture, fisheries, and human settlements (*14*).

A lack of transparency during dam approval processes has raised questions about whether funders and the public are fully informed about risks and long-term impacts on tropical river systems that support livelihoods of millions of people (*3*). Some tropical developing countries lack protocols guiding construction of hydroelectric dams, and many countries exempt small dams (<10 MW) from any formal decision-making process. Even when environmental impact assessments are mandated, millions of dollars may be spent on studies that have no actual influence on design parameters, sometimes because they are completed after construction is under way.

Planners have generally failed to assess the true benefits and costs of large hydropower projects. Returns have usually fallen short of expectations even without adjustment for risk, and an estimated 75% of large dams suffered cost overruns that averaged 96% above the figures used to justify their creation (*15*). Economic projections frequently exclude or underestimate the costs of environmental mitigation, as in the case of the ~$26 billion spent by China to moderate ecological impacts of the Three Gorges Dam (*16*).

Hydropower accounts for more than two-thirds of Brazil's energy supply, and at least 334 new Amazon dams have been proposed (*4*). Impacts of these dams would extend well beyond direct effects on rivers to include forced relocation of human populations and expanding deforestation associated with new roads (*4*). Scheduled for completion in 2016, Brazil's Belo Monte hydropower complex was designed with installed capacity of 11,233 MW, ranking it the

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