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ENERGY

Optimizing Amazonian dams for nature

Algorithms assess opportunities, forgone benefits, and environmental trade-offs

By **Gordon W. Holtgrieve**[1] *and* **Mauricio E. Arias**[2]

Large river systems, particularly those shared by developing nations in the tropics, exemplify the interconnected and thorny challenges of achieving sustainability with respect to food, energy, and water (*1*). Numerous countries in South America, Africa, and Asia have committed to hydropower as a means to supply affordable energy with net-zero emissions by 2050 (*2*). The placement, size, and number of dams within each river basin network have enormous consequences for not only the ability to produce electricity (*3*) but also how they affect people whose livelihoods depend on the local river systems (*4*). On page 753 of this issue, Flecker *et al.* (*5*) present a way to assess a rich set of environmental parameters for an optimization analysis to efficiently sort through an enormous number of possible combinations for dam placements and help find the combination(s) that can achieve energy production targets while minimizing environmental costs in the Amazon basin.

To sustainably develop river systems that maximally and equitably benefit society, decision-making must start with considering the optimal number and geographic configuration of dams. Currently, there are approximately 38,000 dams taller than 15 m

The geographic configuration of dams—such as the Coca Codo Sinclair Dam in Ecuador—throughout a river network determines the overall environmental impact for a given amount of energy produced.

worldwide (*6*) and around 3500 dams greater than 50 MW planned or under construction (*7*). Identifying the number and placement of dams to achieve energy targets, while minimizing negative impacts, is challenging because of the volume of information necessary to spatially represent impacts and the sheer number of ways in which the network of potential dams could be spatially configured.

Flecker *et al.* have provided new tools to assist with this challenge, and the lessons learned are a powerful demonstration of lost opportunities with previous poor dam placement, the importance of transboundary cooperation, and inevitable trade-offs among competing objectives. The relatively small number of dams currently in the Amazon have already set an environmentally inefficient trajectory, especially in terms of threatened fish diversity, and maximum energy benefits with minimal environmental costs can only be realized if countries are willing to cooperate in sharing both those benefits and the costs. Equally if not more challenging, Flecker *et al.* artfully demonstrate that stark trade-offs exist among their five environmental metrics of river flow, river connectivity, sediment transport, fish diversity, and greenhouse gas emissions, and that no dam configuration is optimal for all five aspects. Although the most favorable solutions from the analysis represent minimum environmental costs for a given energy target, it is clear that those costs will not be minimal. Nonetheless, this research suggests that there are still ample opportunities to improve the future path of hydropower development in the Amazon Basin to minimize the environmental impacts, particularly for river flow regulation, sediment trapping, and greenhouse gas emissions.

Power production and environmental impacts are two of many complex factors that inform decisions around dams. Sustainability science is fundamentally transdisciplinary (*8, 9*). If assessments like that of Flecker *et al.* are to be most useful, they must also include more direct socioeconomic metrics of dam construction impacts, ranging from distribution of economic benefits to human food security and population displacement and resettlement. Furthermore, although the broad concept of ecosystem services—economic, cultural, spiritual, and health benefits derived from well-functioning ecosystems (*10*)—is scientifically mainstream and widely understood, it is not clear how specific metrics like fish diversity, riverine connectivity, and flow regulation considered in this study relate to human well-being. These connections need to be better integrated into the regulatory, permitting, and development sectors, which have a more direct influence on where and how many hydropower projects are built.

These points are not lost on the diverse research team of the Flecker *et al.* study, whose members come from a wide array of academic and nongovernmental institutions in the US, Europe, and South America. Included with their research products is a graphical interface of the results aimed directly at transmitting the new knowledge from this highly sophisticated study to the relevant sectors at the appropriate level. These efforts are rarely, if ever, rewarded academically or with funding but are nonetheless essential to bring such research into practice.

The indeterminate nature of scientific research is not an excuse for ignoring what is currently known. Although dam placement on the basis of an existing set of criteria may be inefficient for another yet unquantified criterion, Flecker *et al.* highlight that using tools such as this to quickly and objectively screen the most environmentally harmful dam configurations narrows the potential number of options when considering other, less well quantified criteria. Science alone cannot provide an answer to whether expanding hydropower is the best way to sustainably support the sharply increasing global energy demand. It can, however, provide tools like the one presented by Flecker *et al.* that make the best of the information and technology available to identify trade-offs, highlight options, and facilitate policy discussions that are critically needed not only in the Amazon but also in river basins around the world facing similar sustainable development dilemmas. ■

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BIOMEDICINE

Repairing the blood-brain barrier

Engineered Wnt ligands specifically target blood-brain barrier function

By **Andrew P. McMahon** *and* **Justin K. Ichida**

Specialized vasculature within the brain forms a blood-brain barrier (BBB) that excludes cellular and soluble plasma contents from the inner workings of the central nervous system (CNS) (*1*). Stroke, neurodegenerative disease, and brain tumors result in a loss of BBB properties, which contributes to pathology, arguing for therapeutic approaches to restore BBB functions. Conversely, the BBB poses a problem for drug accessibility. Modulating barrier function can enhance and broaden the effectiveness of therapeutic agents on the CNS (*2*). Development and maintenance of the BBB is regulated by two Wnt ligands, Wnt7a and Wnt7b (*3*). On page 737 of this issue, Martin *et al.* (*4*) describe an elegant molecular dissection of Wnt7 signaling, demonstrating that a single amino acid change in Wnt7a markedly increases its specificity for vascular endothelial cells, resulting in improved outcomes in zebrafish and mouse models of disrupted BBB in tumor growth and stroke.

Cell-cell interactions mediated by Wnt signals regulate an enormous diversity of cellular processes. Similarly, disrupted Wnt signaling has been ascribed to a broad spectrum of disease (*5*). For example, vascular breakdown in ischemic stroke compromises the BBB, disrupting tight junctions between endothelial cells and leading to damage of the underlying nervous systems by infiltrating immune cells and serum factors (*6*). In glioblastoma, tumor growth disrupts the BBB, creating a hypoxic, acidic microenvironment that fuels tumor growth. Vascular normalization improves survival of glioblastoma patients (*7*).

In CNS development, neural progenitor–derived Wnt7 ligands (Wnt7a and Wnt7b),

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