AMAZON WATERS

A NEW GIS-BASED RIVER BASIN FRAMEWORK

FOR AQUATIC ECOSYSTEM CONSERVATION IN THE AMAZON

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A new GIS-based river basin framework for aquatic ecosystem conservation in the Amazon

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Introduction

The Amazon Waters Initiative is a call to action to conceptualize the vast Amazon aquatic ecosystem as a whole, bringing together people to work across a myriad of borders: the borders of the river basins, the riverbanks, the protected areas, the nations of the Amazon, and the institutions that work within it.

Its actions focus on maintaining the integrity of the interlinked and dynamic Amazon freshwater system in order to sustain human wellbeing, wildlife, and the environments on which they depend.

This document summarizes the development and use of a multiple scale GIS-based "roadmap" for spatial analysis in the Amazon basin.

This framework was first published[1] in a peer-reviewed journal, Earth System Science Data by Eduardo Venticinque of Universidade Federal do Rio Grande do Norte; Bruce Forsberg of the Instituto Nacional de Pesquisas da Amazônia; Ronaldo B. Barthem of the Museu Paraense Emilio Goeldi; Paulo Petry of The Nature Conservancy; Laura Hess of the Earth Research Institute; Armando Mercado, Carlos Cañas, Mariana Montoya, Carlos Durigan, and Michael Goulding of Wildlife Conservation Society, in December of 2016. The development of this GIS Framework was coordinated by Michael Goulding. It is available free of charge at the following link: http://www.earth-syst-sci-data.net/8/651/2016/

This scalable basin framework[2] is a contribution of the Amazon Waters Initiative and SNAPP, and a product of a 15+ year collaboration between hydrologists, limnologists, and freshwater ecologists. Framework can be downloaded at
https://knb.ecoinformatics.org/#view/doi:10.5063/F1BG2KX8

1. Venticinque, E. and Forsberg, B. and Barthem, R. and Petry, P. and Hess, L. and Mercado, A. and Cañas, C. and Montoya, M. and Durigan, C. and Goulding, M.: An explicit GIS-based river basin framework for aquatic ecosystem conservation in the Amazon, Earth System Science Data, 8, 2,651-661, 2016.
2. Venticinque, E., Forsberg, B., Barthem, R. B., Petry, P., Hess, L., Mercado, A., Canas, C., Montoya, M., Durigan, C., and Goulding, M.: SNAPP Western Amazon Group – Amazon Aquatic Ecosystem Spatial Framework, KNB Data Repository,doi:10.5063/F1BG2KX8, 2016.

General description of the database

River basins are the most natural spatial units of aquatic ecosystems, and are thus generally used by the agencies or authorities that manage waters in Amazonian countries.

Most basin classifications used in the Amazon (such as the Pfafstetter methodology)[3] do not consider the main stem and its associated floodplains as a unit. Yet, these areas contain the most productive river and wetland habitats and should be managed in the same way as large basins are. This database includes the main channel and surrounding floodplains of the Amazon River and its largest tributaries as discrete sub-basins in a regional basin hierarchy. This creates a new spatially explicit integrated river basin framework making it easier to manage and conserve the Amazon fluvial ecosystem at multiple scales **(Fig. 1).**

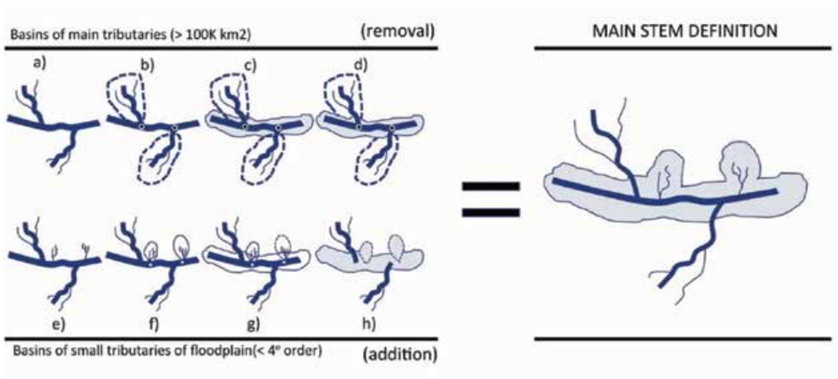


Fig. 1. Schematic definition of main stem sub-basins.

How the river floods pulse in time and space influences inundation patterns in floodplain environments and play a fundamental role in sustaining the diversity and productivity of this habitat's biodiversity and the livelihoods of human populations throughout the Amazon. Infrastructure development, including the construction of new dams, roads, and hidrovías across the basin, together with accelerating land use and climate change, threaten to disrupt this complex system of water and wildlife, with predictable negative consequences for the biota and river dwelling populations that depend on its integrity. The conservation and management of the natural resources and services provided by this ecosystem will require a standard hydrological framework that spans the entire Amazon region, specifically adapted for this objective.

Two types of water data are included in this spatial framework for the Amazon Basin (both expanded upon in later sections):

1. Basins (*Polygon*): a hierarchical river basin classification and delineation of main stem floodplains. Main stems are the large downstream segments of the Amazon River and its major tributaries. Although not basins, per se, these main stem sub-basins contain large areas of wetlands and are important for fisheries production and aquatic biodiversity in the Amazon Basin. The basin classification contains seven basin levels of decreasing area, including main stem floodplain sub-basins, thus allowing data analyses at variable scales.

2. Rivers (*Line*): a new high density drainage network containing important geographical attributes, including stream order (1st – 11th order), tributary name (6 – 11th order), river type (6 – 11th order) and distance above the Amazon River mouth (4 – 11th order).

3. Developed by Otto Pfafstetter in 1989, is a methodology for assigning watershed IDs based on the topology of the land surface. The system is hierarchal, and watersheds are delineated from junctions on a river network: Level 1 watersheds correspond to continental scale watersheds and higher levels (levels 2, 3, 4, etc.) represent ever-finer tessellations of the land surface into smaller watersheds, which are sub-watersheds of lower level watersheds. (Pfafstetter, O., 1989, "Classification of hydrographic basins: coding methodology", unpublished manuscript, DNOS, August 18, 1989, Rio de Janeiro).

Basins

Development of basin hierarchy

Seven different scales or hierarchical levels are delineated in our basin hierarchy, denominated Basin Level 1- Basin Level 7 (BL1-BL7). **Fig 2**

Figure 2. Cartographic representation of Amazon Basin (working area) classification data of first 4 levels.

BL = Basin Level

Amazon Region

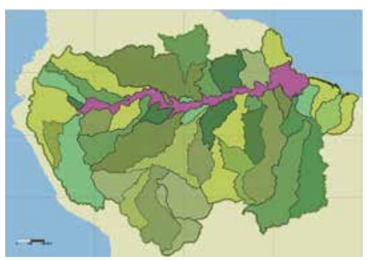
Amazon Basin

Amazon Main Stem

BL1

BL2

BL3



BL4

Basin code generation: Basin codes for BL1 and BL4 basins were derived from the names of the principal rivers in each polygon. Codes for BL5 – BL7 basins were created combining the associated BL2 basin name with the ID numbers generated automatically when each basin was delimited.

Basin Level 1 (BL1): Regional Basins – This level divides the working area into 3 drainage polygons: one large polygon containing the Amazon and Tocantins river basins; and two smaller ones containing the northern and southern coastal basins draining directly into the Atlantic.

Basin Level 2 (BL2): Major Amazon Tributary Basins – This level delimits all tributary basins larger than 100,000 km² (main basins) whose main stems flow into the Amazon River main channel, as well as an Amazon River Main Stem polygon that consists of the open waters of the Amazon River, its floodplain and adjacent small tributary basins.

Basin Level 3 (BL3): Major Tributary Basins – This level delimits all basins larger than 100,000 km², including: those that do not flow directly into the Amazon River main channel; all tributary basins larger than 10,000 km² and less than 100,000 km² that flow into the Amazon River Main Stem; and a single central floodplain drainage polygon.

Basin Level 4 (BL4): Minor Tributary Basins - This level delimits all tributary basins greater than 10,000 km² and less than 100,000 km². Floodplain drainages include all tributaries with basins less than 10,000 km² flowing toward the floodplain at high water.

Basin Levels 5-7 (BL5 – BL7): Minor sub-basins - The remaining three basin levels (BL5, BL6 and BL7) were created by subdividing BL4 basins into drainage subunits with threshold sizes of 5,000, 1,000 and 300 km², respectively.

Basin grids for Amazon tributaries (BL2), major tributaries (BL3), and minor tributaries (BL4) were created from the flow direction grid and a point shapefile for basin outlets. The database includes information on areas and the name of the principal tributary of all major and minor tributary basins. Sub-basin grids with thresholds of 5,000 (BL5), 1,000 (BL6) and 300 km² (BL7) were created for the entire Amazon Basin. These sub-basin grids were then transformed into separate polygons using a tool that processes this information into a file outlining where water is drained. General characteristics and statistics for each basin level are summarized in **Table 1**.

Table 1 - General description of catchments system for Amazon Region.

General description	Level	N catchments	Average area (km²)	Main Stem
Amazon and coastal basins	**BL1**	3	N/A	No
Major Amazon tributary basins > 100,000 km²	**BL2**	21	385,386	Yes
Major tributary basins > 100,000 km²	**BL3**	38	170,277	Yes
Minor tributary basins < 100,000 km² & >10,000 km²	**BL4**	199	36,625	Yes
10,000 km² < Sub-basins> 5000 km²	**BL5**	1075	6,811	No
5000 km² < Sub-basins > 1000 km²	**BL6**	4606	1,589	No
1000 km² < Sub-basins > 300 km²	**BL7**	15269	479	No

Rivers

Drainage network development

We built the stream system after generating a digital elevation model (DEM; a geospatial layer that describes the elevation gradients), a flow direction file (a file that specifies how water would flow, given the elevation), and a flow accumulation file (a file that shows how water would accumulate, given the flow and elevation) for the working area. The "stream threshold" value determines the size of the upstream drainage area at which the stream grid begins to be delineated, and consequently the final resolution of the drainage network. A stream grid with an upstream stream threshold of approximately 81 ha was used together with the flow direction grid to create an ordered high-resolution stream grid.

The stream order varied from 1st to 11th in this product. It is probably underestimated by 1st order, since the drainage areas of first order streams (permanent streams with no permanent upstream tributaries) tend to vary from 10-50 ha in the central Amazon Basin. Assuming that this is correct, the smallest streams in the stream network developed here would be approximately 2nd order and the Amazon River main channel near its mouth would be 12th order. Three different stream network shapefiles were created from this high-resolution product, containing streams from 1st-11th order, 6 – 11th order and 7 – 11th order, respectively. Tributary names, derived from existing databases, were added to the 6 – 11th order river network.

The shapefile containing 1st-11th order streams was filtered to remove 1st to 3rd order streams generated on known open water surfaces and wetlands. They were generated because of the inaccuracy of the DEM and the flow direction grid. These anomalies consisted of spurious low order stream segments, generated predominantly in low relief wetland environments where variation in elevation was either extremely low (open water environments) or due primarily to variations in vegetation height. While most of the anomalous segments were removed by the filter, some are still apparent at higher resolutions.

Classification of river type

Water type varies considerably in the Amazon River system and has been shown to have a major influence on biogeochemical processes and on the distribution and dynamics of aquatic habitats and biota.

There are three main types of rivers in the Amazon Basin based on natural differences in water color and quality: 1) whitewater rivers, which are neutral in pH and are rich in suspended sediments and nutrients, 2) blackwater rivers, which are low in pH, nutrients, and suspended sediments, but high in dissolved organic carbon; and 3) clearwater rivers, which are low to neutral in pH, and low in nutrients, suspended sediments, and dissolved organic carbon. We defined water type (white, black or clear) in 6 – 11th order rivers based on regional knowledge and visual analysis of optical imagery of various resolutions available through Google Earth (Google Inc). The resulting assignment of river types based on water type is shown in Figure 3. This is a first approximation based on current knowledge.

Definition and mapping of fish spawning nodes

Many migratory characiform fish species spawn, or release eggs, where whitewater and blackwater or clearwater rivers meet. These fish spawning nodes were identified and incorporated in a shapefile for 6th – 11th order rivers. The most important areas among these were then identified by intersecting spawning nodes with the sub-basins or main stem drainages important for commercial fishing **Fig. 3**.

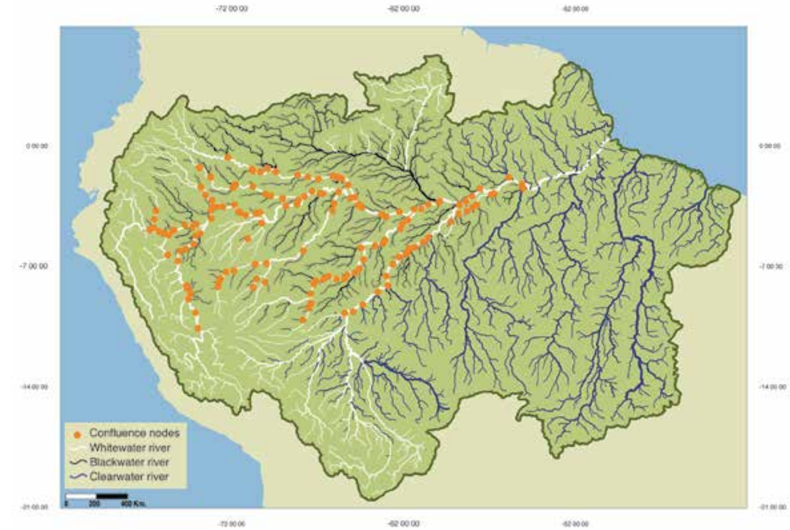


Figure. 3. Map of important confluence areas where fish deposit eggs and humans catch fish.

River distances

Distances along the river network from the mouth of the Amazon River to specific points in the river system can be important for characterizing spawning routes, calculating how long a species stays in a particular place, calculating the velocities of fish larvae/juvenile during downstream migrations, and the presence of other materials, such as sediments, in the system. The data provide not only distances to specific points from the Amazon River mouth but also to distant regions. Distance values and stream order are included in the segment attribute table of the final river network shapefile in the database.

General conclusions

This multi-level basin hierarchy and classified river network provides a new tool that reflects a vision of the Amazon region as connected by its waters. Its architecture allows integrated monitoring and management of aquatic ecosystems at distinct spatial scales. The principal data products provided in the GIS include:

1. A multi-level basin hierarchy specifically designed for the conservation and management of river basins and floodplain environments at a variety of basin and sub-basin scales.

2. A high resolution (1st-2nd order), spatially uniform, and ordered drainage network for the Amazon Basin and its adjacent coastal basins (Coastal North, Coastal South).

3. A first approximation of river types based on water type as a proxy for distinct chemical characteristics included as an attribute for 6-11th order tributaries.

4. Estimates of the distance of individual stream segments from the mouth of the Amazon River, included as an attribute for 4-11th order streams in the Amazon basin.

5. A point shape file indicating confluences (nodes) of different river types that are critical spawning zones for migrating fish species.This regional hydrological database provides a coherent framework for the integration and analysis of a wide array of spatial data, critical for management and conservation of this valuable fluvial ecosystem.

Photo: Walter Wust

Next Steps

The GIS-based river basin framework for aquatic ecosystem conservation in the Amazon was developed as an iterative framework for addressing a wide array of conservation challenges. Fisheries and wetlands were the focus of initial analyses because of their critical role in food security in the Amazon Basin. We will continue to build on these aspects with analyses of protected areas, indigenous territories and infrastructure impacts on waters, wetlands and priority basins.

The Amazon Waters Initiative team will also work closely with a variety of stakeholders to implement the Framework for environmental monitoring and planning of aquatic ecosystems and their biodiversity. We anticipate that governmental agencies, NGOs, universities and other institutions will adapt various tools in the Framework for their specific interests concerning spatial analyses at various scales of basins in the Amazon.

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