Rapid large-scale hydrological and geomorphic response to deforesation in a large tropical fluvial system. NASA-LCLUC NG06D51G

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Deforestation of the Brazilian savanna biome (locally called Cerrado; Figure 1) has been rapid and extensive: more than 60% of the original 2,000,000 km^2 has been converted to pasture and agriculture since 1960. Land cover changes lead to important changes in the hydrologic, geomorphologic, and biochemical states of river systems: decreasing evapotranspiration on land, increasing river discharge, erosion and sediment flux, and altering river and floodplain morphology. The Araguaia River (Figure 1) offers a unique opportunity to evaluate the impact of deforestation on a large tropical river.

- The drainage area has undergone a rapid conversion from native Cerrado
- Continuous discharge measurements have been recorded at numerous sites since deforestation began

Here we present evidence of changes to the land cover, channel morphology, sediment flux, and discharge of a 120,000 km^2 area of the Araguaia River basin and quantify the role that deforestation has played in these changes. The results represent one of the more spectacular examples of rapid large-scale hydrological and geomorphic response to deforestation in a large tropical fluvial system.

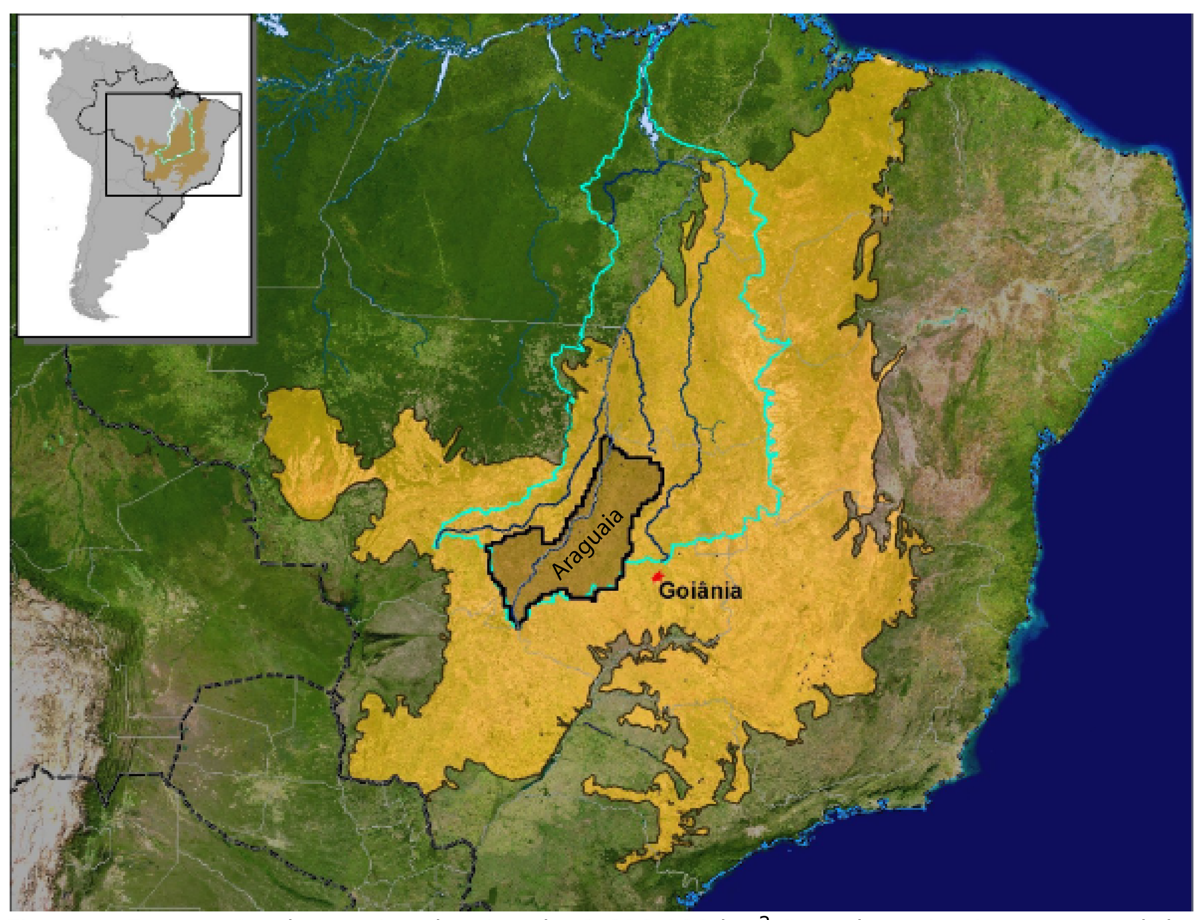

Figure 1. Eastern South America showing the 2,000,000 km^2 Cerrado region in orange and the middle and upper Araguaia River basin in brown.

Land Cover:

23 CBERS II – CCD 20m spatial resolution images (China Brazil Earth Resource Satellite) acquired August and September of 2006 (dry season), were used to map the remnant Cerrado and forested areas of the Araguaia basin. The images were made available by the Brazilian Space Research Institute (INPE) (see http://www.dgi.inpe.br/CDSR/).

The CBERS scenes, geocoded and mosaiced, were spectrally enhanced via a normalized difference vegetation index (NDVI) transformation, followed by the slicing of the resultant NDVI image into three thematic classes: 1) remnant vegetation, 2) converted areas, and 3) water bodies (Figure 2).

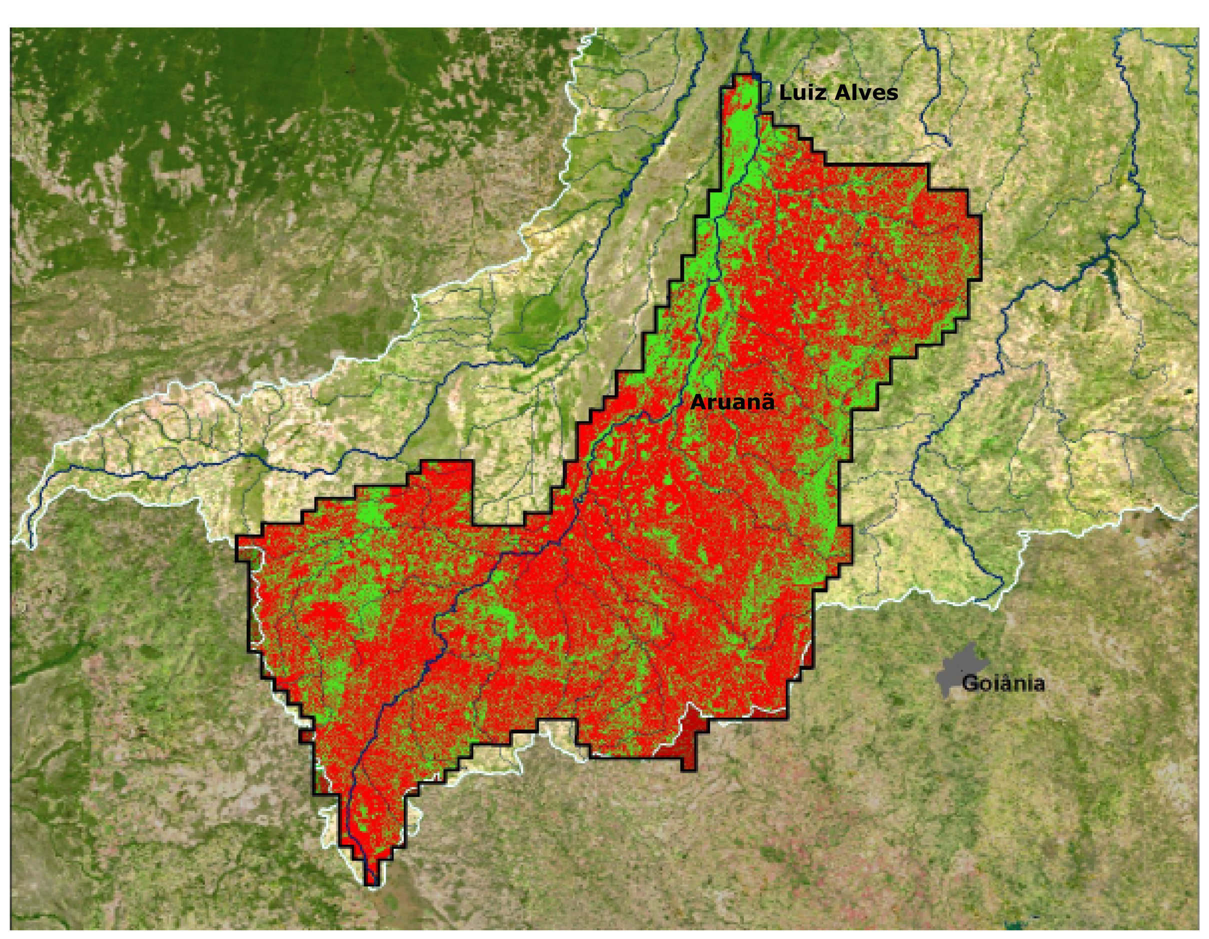

Figure 2. Close-up of the middle and Upper Araguaia River basin showing the CBERS-derived classification of remnant Cerrado (green) and altered lands (red). About 62% of the basin vegetation and 45% of all riparian zones have been altered by 2006

A summation of the classes shows that 38% of the 120,000 km^2 land area is in native Cerrado vegetation, while 62% has some kind of environmental disturbance, ranging from major converted areas to local use by small holders. About 45% (or 6,353 km^2) of the area within a 100 m buffer of major streams is already converted from its native state.

River morphology:

Landsat MSS, TM 5, and ETM+ images from many years, SLAR mosaics from 1973, topographic charts, aerial photographs from 1965, and fieldwork were used to quantify the changes to stream morphology that have occurred since 1965, such as variability in the number and size of islands, type and size of sand bars, channel width, and number of secondary channels.

The results indicate relatively small changes when comparing the 1965 data with 1977 data.

- Islands are relatively stable, with only small changes (Figure 3D).
- Large lateral bars and an increasing number of middle channel bars are present (Figs 3 A & C).

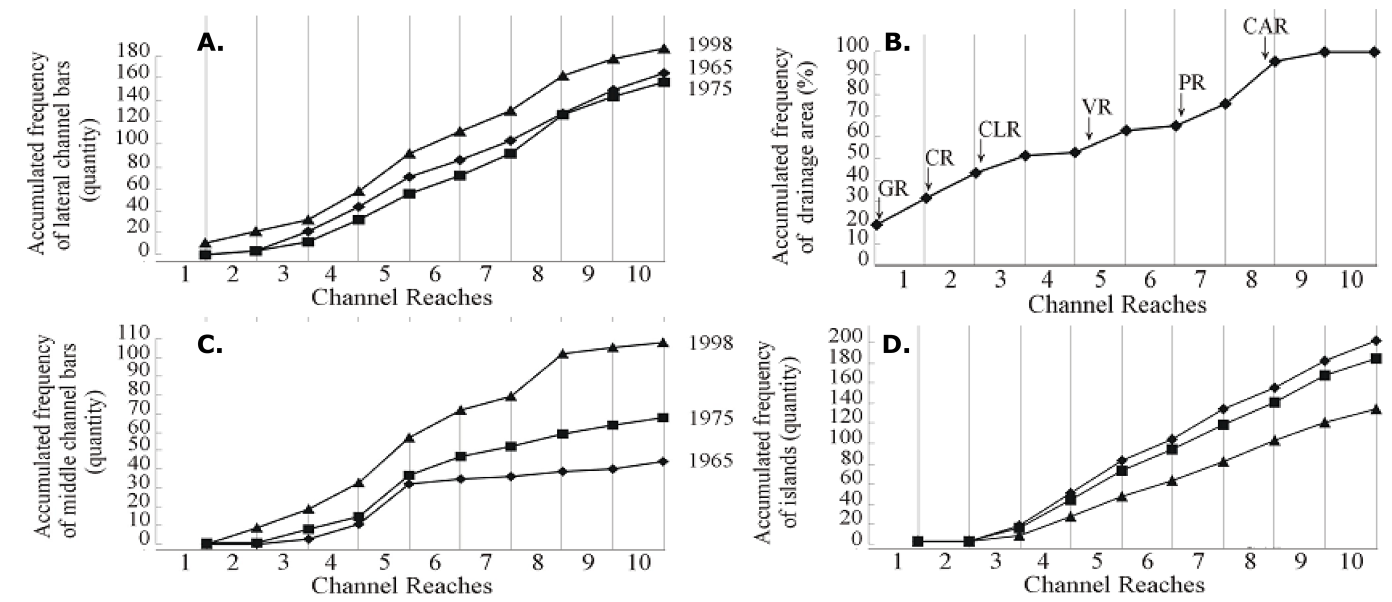

Figure 3. Graphs showing the cumulative frequency of A) lateral channel bars, B) drainage area, C) middle channel bars, and D) islands from upstream (GR) to downstream (after CAR) for 1965, 1975, and 1998.

By 1998 the changes are remarkable (Figures 3 & 4).

- The number of islands decreased substantially from 209 to 137 (Figure 3D) as a result of infilling of secondary channels by increased sediment flux and destruction of small islands along the main channel
- Middle channel bars increased significantly (by 280% from 1965 to 1998) but the individual bars were reduced in size.

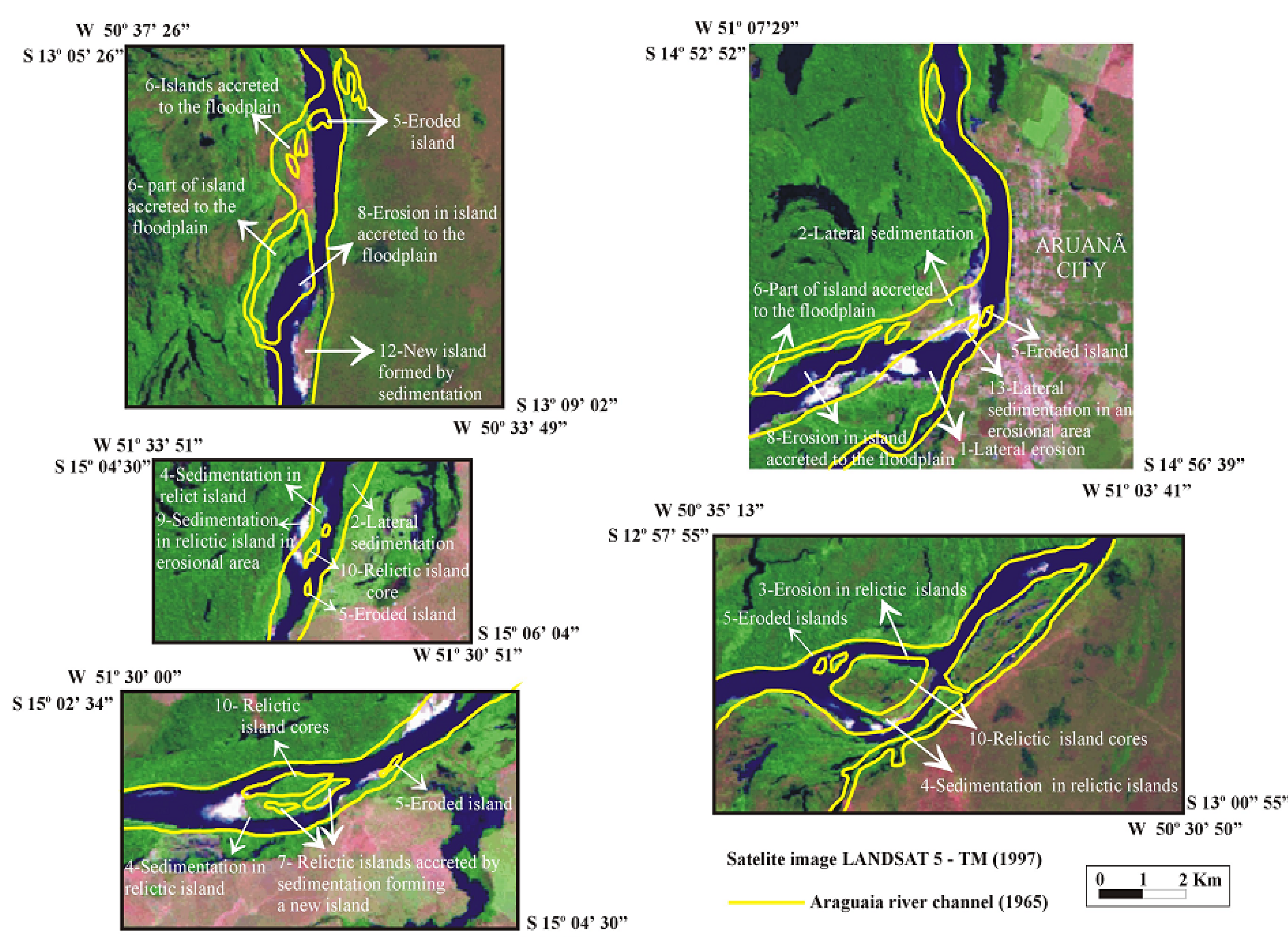

Figure 4. 1997 LANDSAT-5 TM images of 5 reaches of the Araguaia River with the channel dimensions in 1965 superimposed in yellow. The 1965 channel is derived from aerial photographic images.

Fieldwork was conducted by boat along the entire 570km length of the studied area from 1999 to 2007 to quantify some of the changes to the sediment flux (Figure 5). The results indicate:

- The river is transporting an average of more than 8Mt/y of bed load sediments at Aruanã, a 28% increase since the 1970s.
- A mass balance of the total change in sediments stored on the floodplain shows a net of about 240 million tons of sediments have been stored in the alluvial plain from 1965 to 1998 (Figure 5).

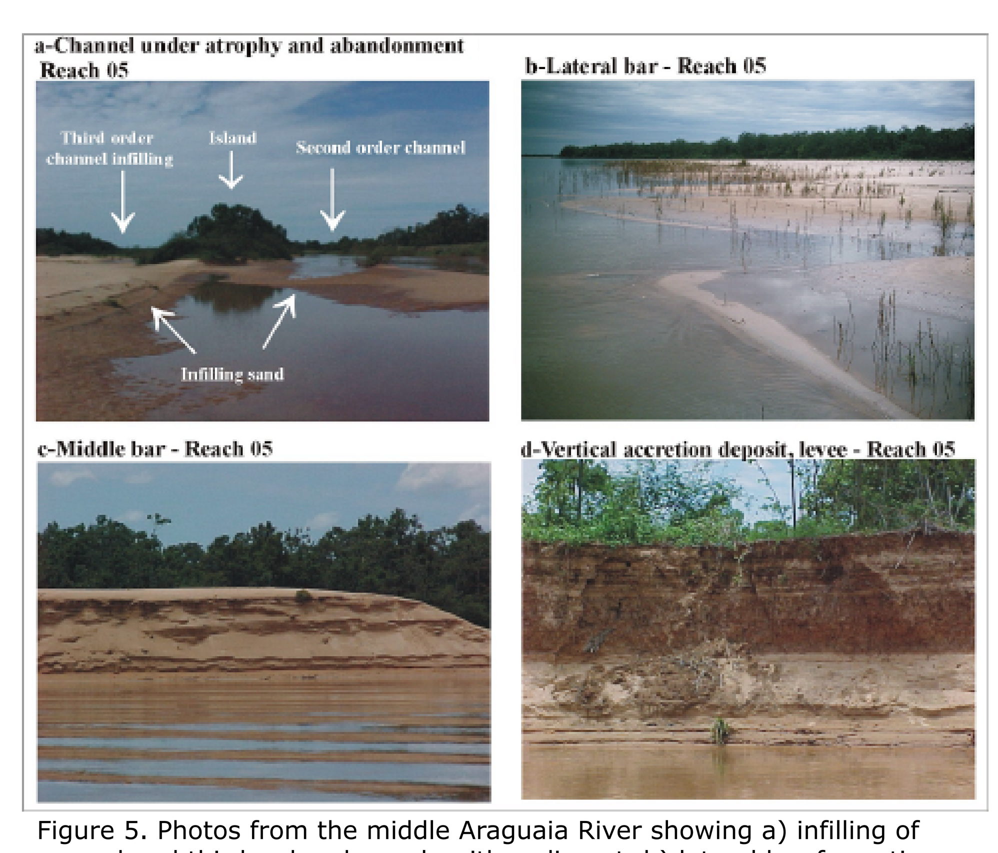

Figure 5. Photos from the middle Araguaia River showing a) infilling of second and third order channels with sediment, b) lateral bar formations, c) typical middle bar, and d) sediment deposition since 1965.

In summary: With increased conversion of the landscape to agriculture, there has been a very large increase in the amount of sediment in the river. The river has responded to this increase quickly: the river is storing more sediments by infilling secondary channels, accreting the more stable lateral bars, and eliminating some obstacles such as the smallest islands, which means that the river, that formerly had a multi-channel pattern is in the process of opening a central corridor to more effectively transport the increased sediment supply.

Discharge:

We analyzed discharge data collected for the period 1970-2000 at the 77,000 km^2 Aruanã watershed by Agência Nacional de Aguas (ANA).

- Mean annual discharge at Aruanã increased by 26% -- from 988 m^3/s in the decade 1970-1979 to 1231 m^3/s for the decade 1990-1999 (Figure 6A).
- Discharge increased in all months except November (Figure 6A), by about 30% in the core of the wet season (Jan-Mar) and dry season (April-Aug).

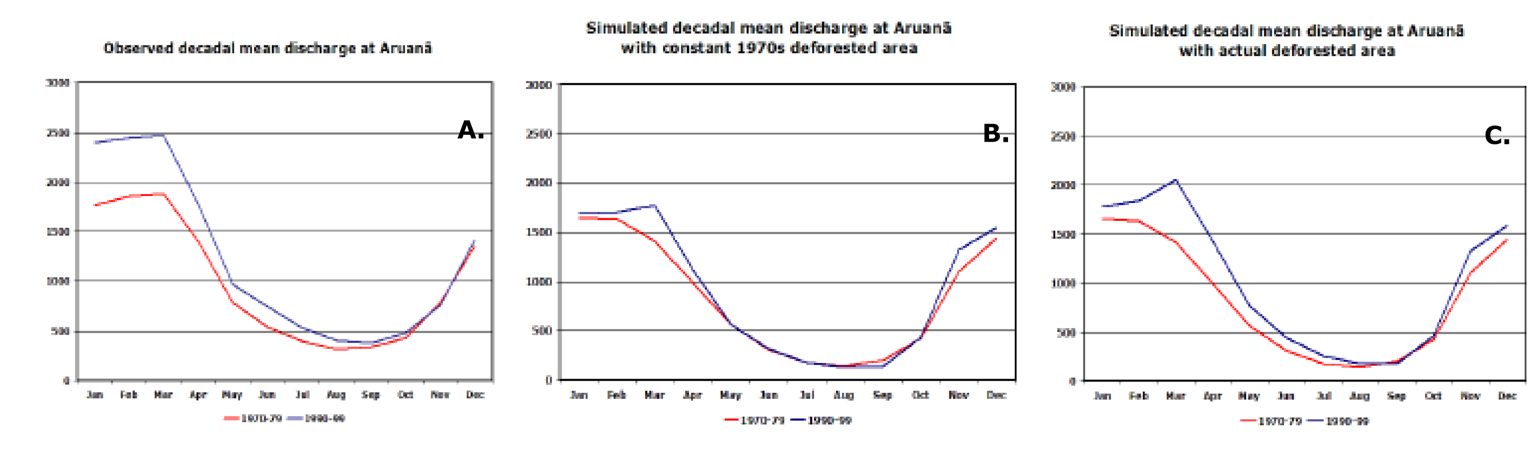

Figure 6. Mean discharge for the period 1970-79 (red) and 1990-1999 (blue) at Aruanã for A) observed, B) simulated with 1970s vegetation, and C) simulated with the vegetation corresponding to the decade.

The land surface model IBIS was used with the river transport model THMB to evaluate the influence of historical deforestation on the discharge of the Araguaia River.

The river discharge was simulated for the entire basin for two land cover scenarios:

- An estimate of the natural and agricultural landscape in the 1970s, in which about 30% of the basin is in agriculture
- An estimate in the 1990s, in which about 55% of the basin is in agriculture (Figure 7).

The simulations were run with identical climate data for the period 1970 to 2000 and the decadal mean discharge for the 1990s and 1970s were compared. Because all other aspects of the simulations are identical, any differences in the simulated river discharge between the two scenarios are a result of the land cover changes alone.

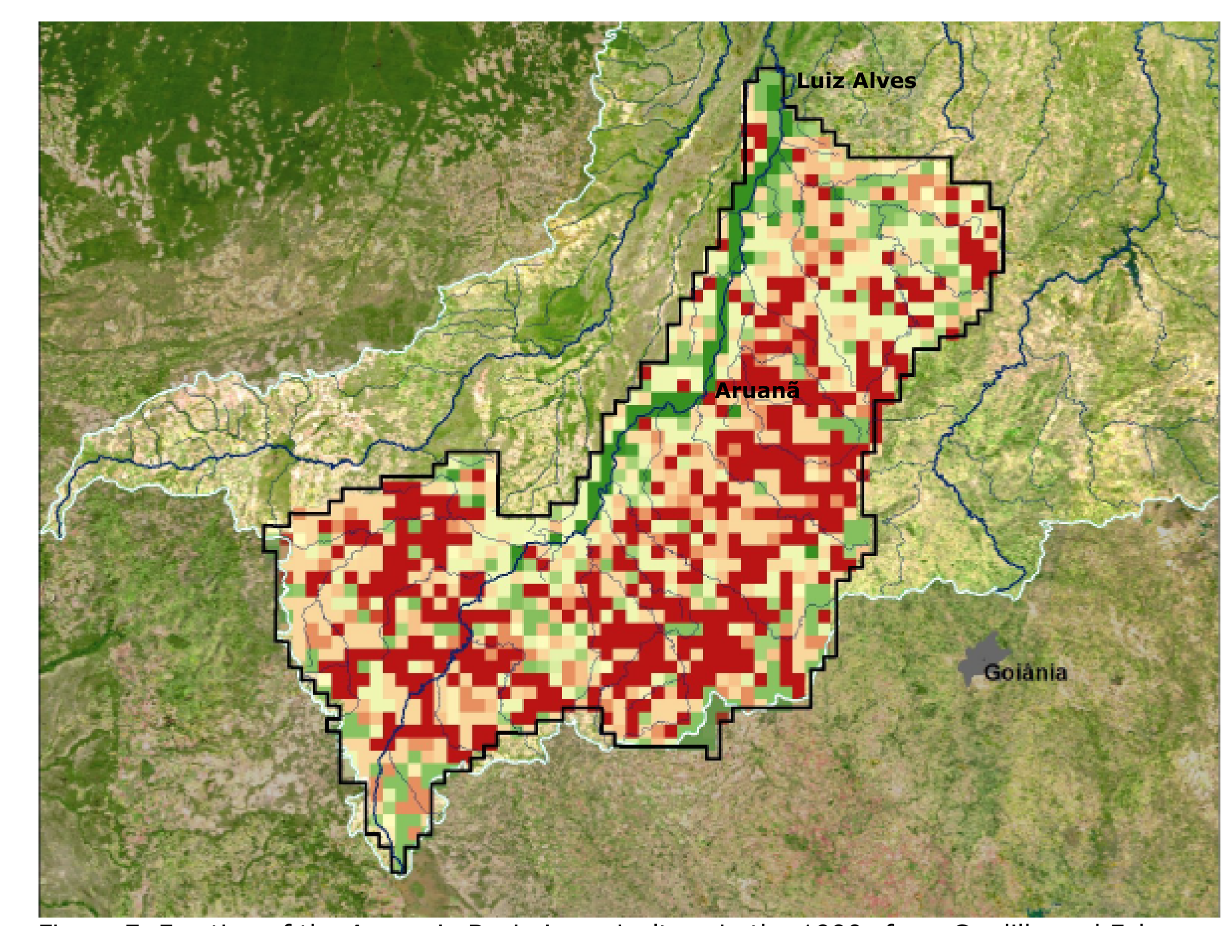

Figure 7. Fraction of the Araguaia Basin in agriculture in the 1990s from Cardille and Foley, 2003, with red being high agriculture fraction, and green being low. The agricultural fraction is at 5-minute horizontal resolution and is derived by merging AVHRR-derived land cover classes with municipio-level agricultural census data.

The results show the impact of land cover changes.

- Holding 1970's land cover constant, mean discharge increased 10% by the 1990's due to increased precipitation (Figure 6B).
- Allowing both land cover and climate to change from the 1970's to the 1990's, mean discharge increased by 23% (Figure 6C), which agrees with the observed 26% increase.
- Therefore, land use change contributed about 1/2 of the increase in river discharge over 3 decades.

In summary, from the 1970's to the 1990's the observed discharge increased by about 26%. The model results are in agreement with the observations and suggest that more than half of the observed increase in discharge between the 1990's and 1970's is a direct result of conversion of the landscape to agriculture.

CONCLUSIONS

Satellite observations, extensive fieldwork and numerical modeling studies were used to quantify the physical changes to the Araguaia River system that have occurred in the last 40 years. Fundamental changes to the terrestrial and aquatic environments include:

- As of 2006 62% of the land has been converted to agriculture.
- Sediment flux within in the Araguaia River increased by 30%.
- The river is re-organizing its physical structure to accommodate the increased sediment; with a central channel being carved from what was once a multi-branching river.
- Discharge since the 1970s has increased by 26%.
- Simulations indicate that more than ½ of change in discharge is attributable to changes in land cover.