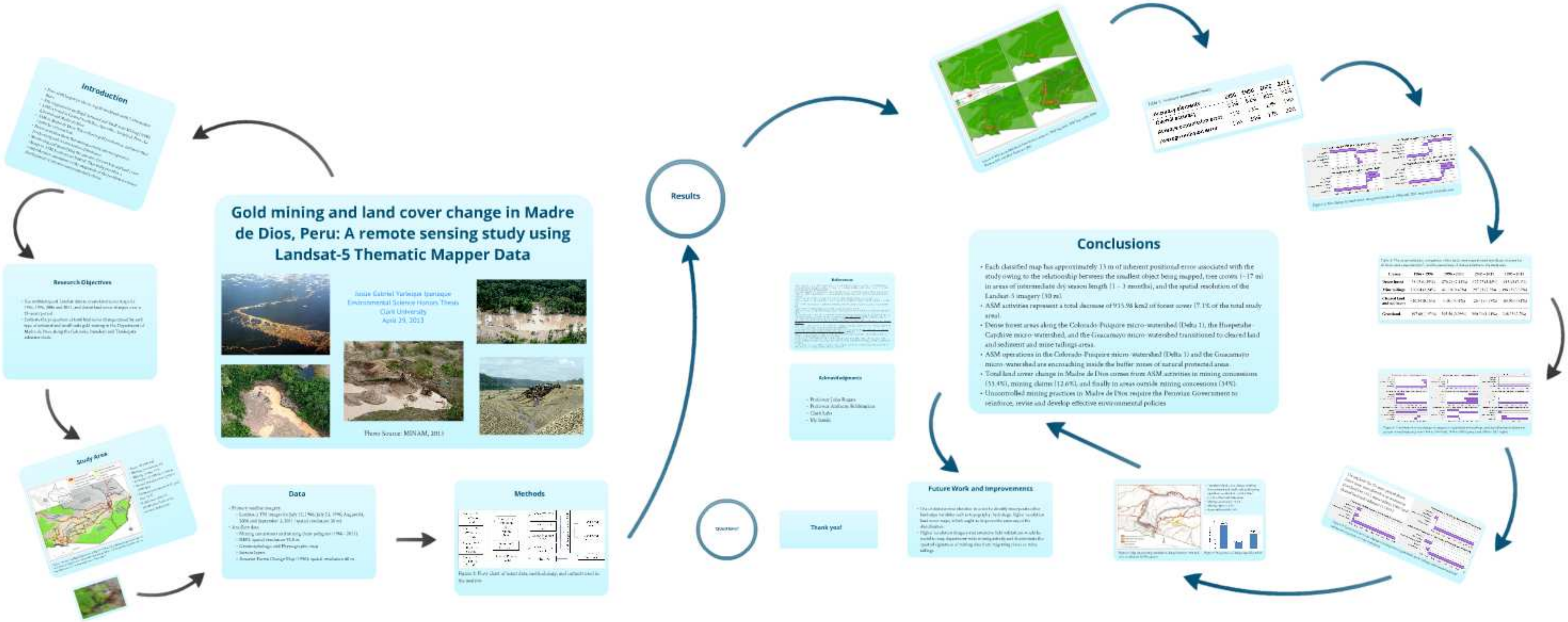
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Josue Gabriel Yarlequé Ipanaqué
Environmental Science Honors Thesis
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April 29, 2013
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• ASM activities represent a total decrease of 915.98 km2 of forest cover (7.1% of the total study area).
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Gold mining and land cover change in Madre de Dios, Peru: A remote sensing study using Landsat-5 Thematic Mapper Data

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Introduction

- Peru: sixth largest producer of gold worldwide with 7.68% market share.
- 20% originates from illegal Artisanal and Small-scale Mining (ASM).
- ASM is found in Central South (Ica, Ayacucho, Arequipa), Puno, La Libertad and Madre de Dios
- ASM in Madre de Dios: 70% of Peru's gold production, and more than 32,000 ha of forest loss.
- Previous studies show that mining activity affects vegetation productivity and creates surface disturbance.
- Monitoring and quantifying the amount of forest loss and land cover change in ASM locations are limited. This study provides a comprehensive assessment of the magnitude of the problem for future development of effective environmental policies.

Research Objectives

- Use multitemporal Landsat data to create land cover maps for 1986, 1996, 2006 and 2011, and detect land cover changes over a 25-years period.
- Estimate the proportion of total land cover change caused by each type of artisanal and small-scale gold mining in the Department of Madre de Dios, along the Colorado, Inambari and Tambopata subwatersheds.

Study Area

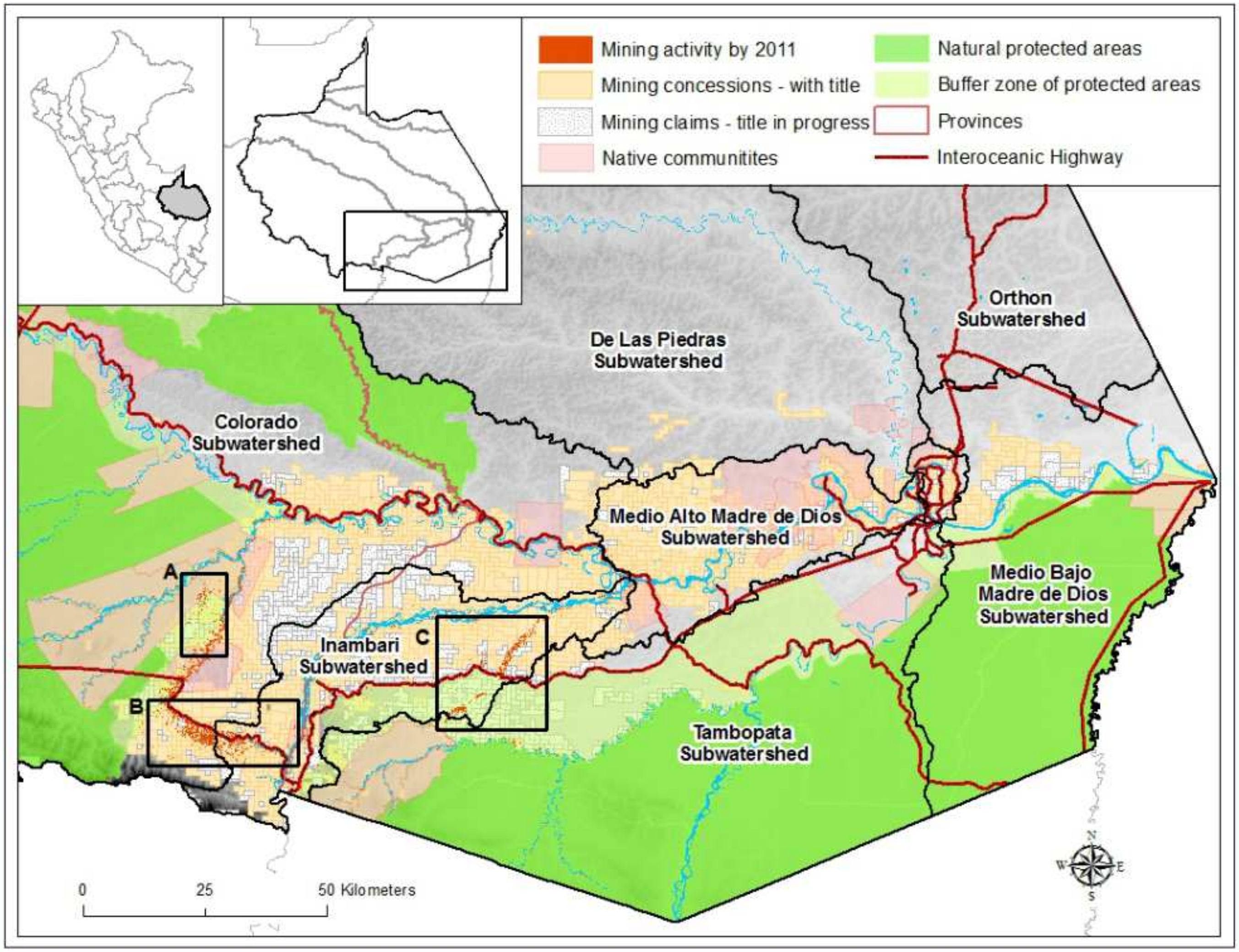


Figure 1: Study Area Map: Department of Madre de Dios, Peru. Mining areas denoted by "A", for Colorado-Puiquire micro-watershed, known as Delta 1; "B" Huepetuhe-Caychive micro-watershed; and "C" for Guacamayo micro-watershed.

- Area: ~85,000 km^2
- Mining concessions: 6%
- Mining claims: 3.5%
- Altitude: ~15,000 m to 300 m
- Annual precipitation: 1,500 to 3,000 mm
- Temperature: min 16.8 °C, and max 32 °C
- Population: 109,555 inhabitants, 0.4% of the national population

Data

- Primary satellite imagery:
    - Landsat-5 TM images for July 12, 1986; July 23, 1996; August 04, 2006 and September 3, 2011 (spatial resolution 30 m)
- Ancillary data:
    - Mining concessions and mining claim polygons (1986 - 2011)
    - DEM: spatial resolution 92.8 m
    - Geomorphologic and Physiographic map
    - Stream layers
    - Amazon Forest Change Map (1990): spatial resolution 60 m

Methods

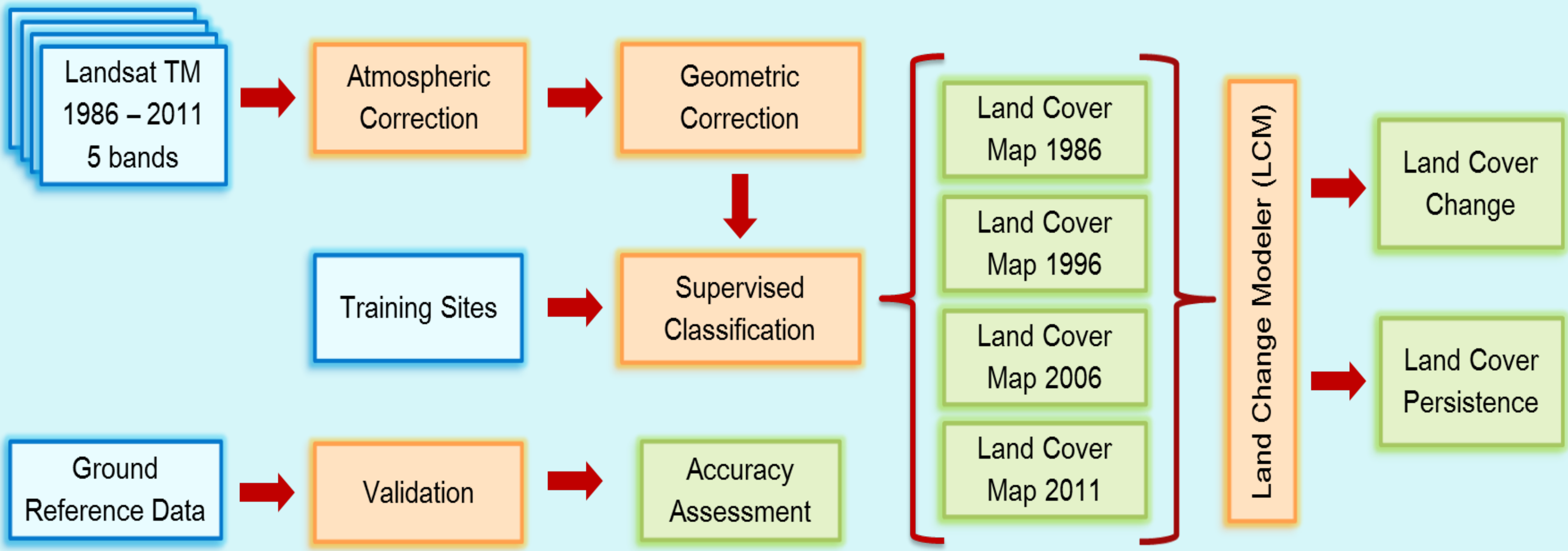


Figure 2: Flow chart of input data, methodology, and outputs used in the analysis

Results

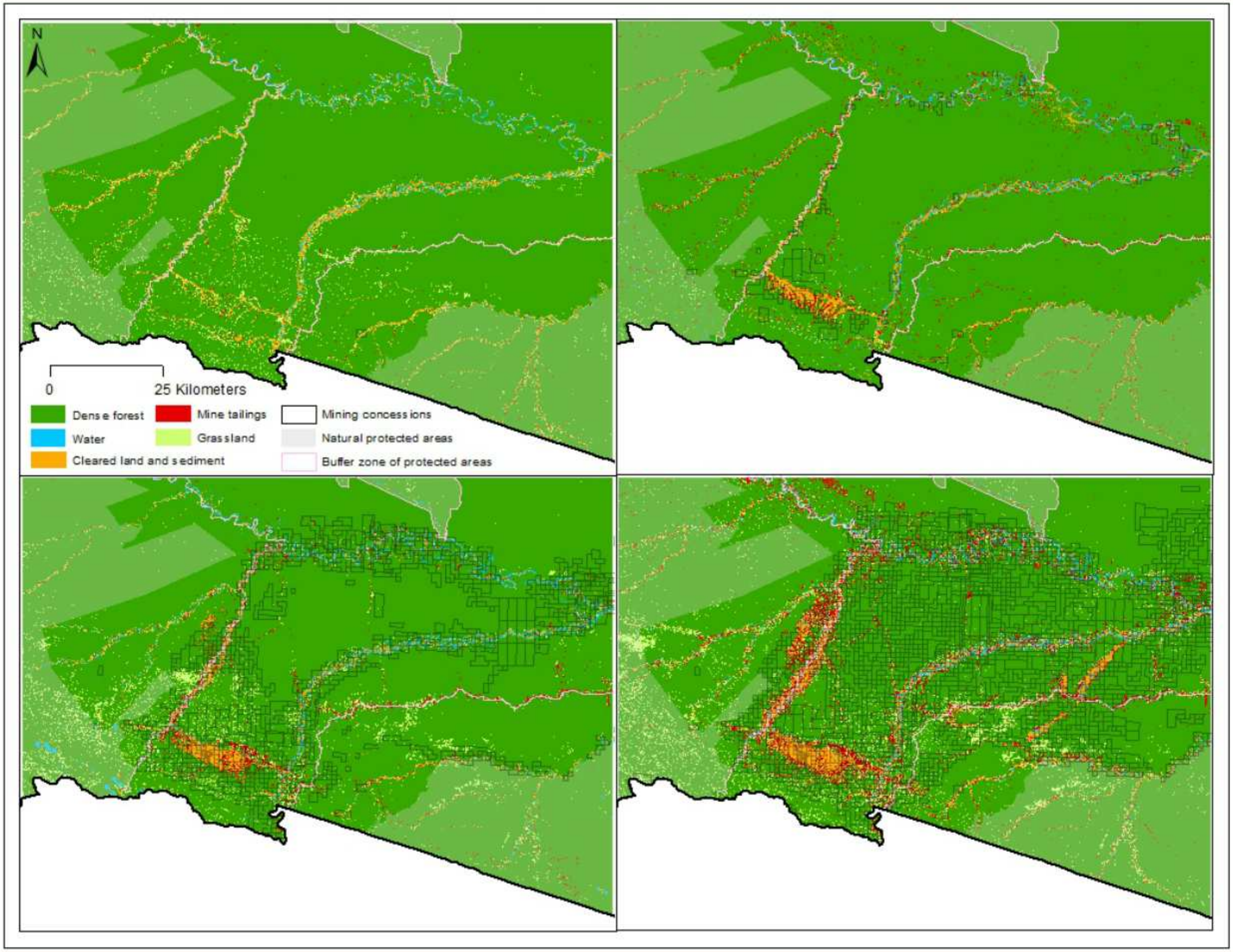


Figure 4: Maximum likelihood classification maps for 1986 (top left), 1996 (top right), 2006 (bottom left) and 2011 (bottom right).

Table 1: Accuracy assessment results

Accuracy elements	1986	1996	2006	2011
Overall accuracy	84%	81%	83%	82%
Average commission error	17%	23%	19%	18%
Average omission error	15%	18%	17%	20%

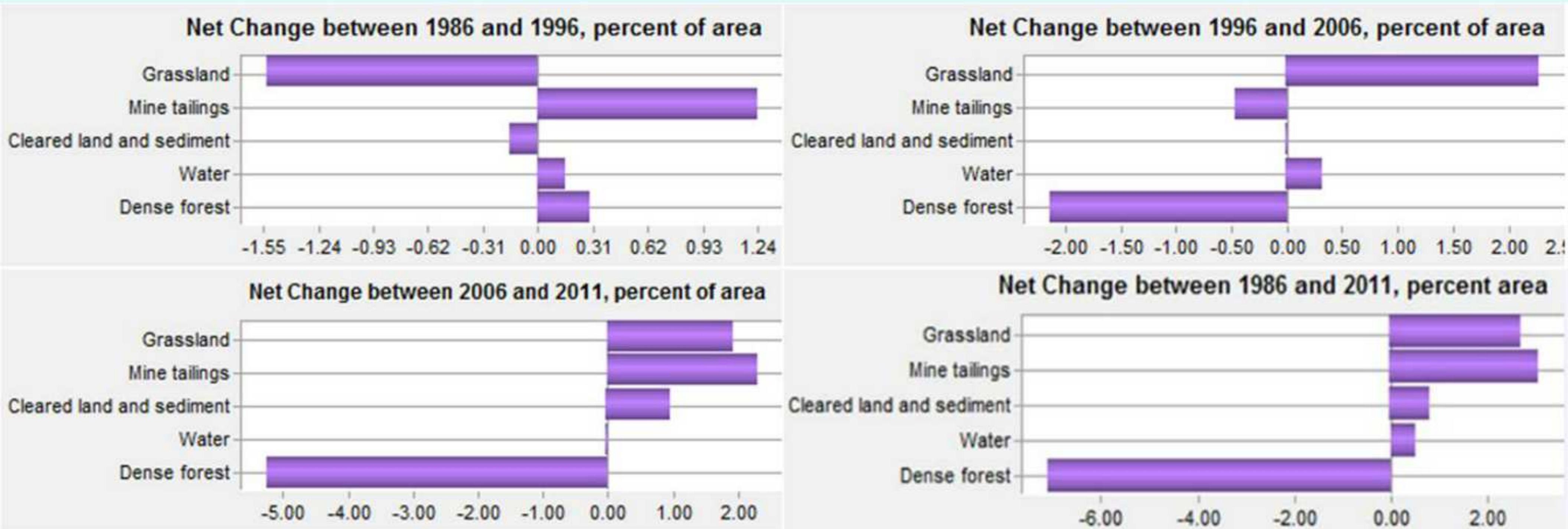


Figure 5: Net change in land cover categories between 1986 and 2011 in percent of study area.

Table 2: The cross-tabulation comparison of the land cover maps showed significant changes for all land cover categories (km^2), and the percentage of change relative to the study area.

Classes	1986 - 1996	1996 - 2006	2006 - 2011	1986 - 2011
Dense forest	38.05 (0.29%)	-276.25 (2.14%)	-677.77 (5.25%)	-915.98 (7.1%)
Mine tailings	160.04 (1.24%)	-61.10 (0.47%)	297.21 (2.3%)	396.15 (3.07%)
Cleared land and sediment	-20.34 (0.16%)	-1.01 (0.01%)	126.41 (0.98%)	105.06 (0.81%)
Grassland	-197.60 (1.53%)	295.56 (2.29%)	250.39 (1.94%)	348.35 (2.7%)

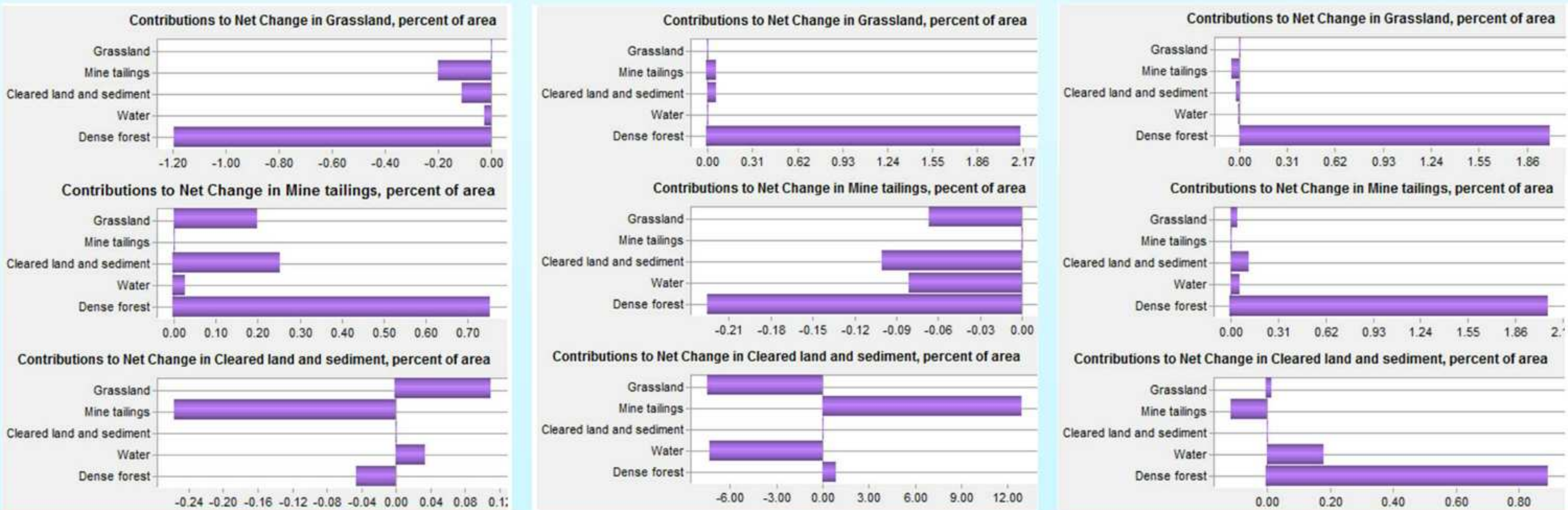
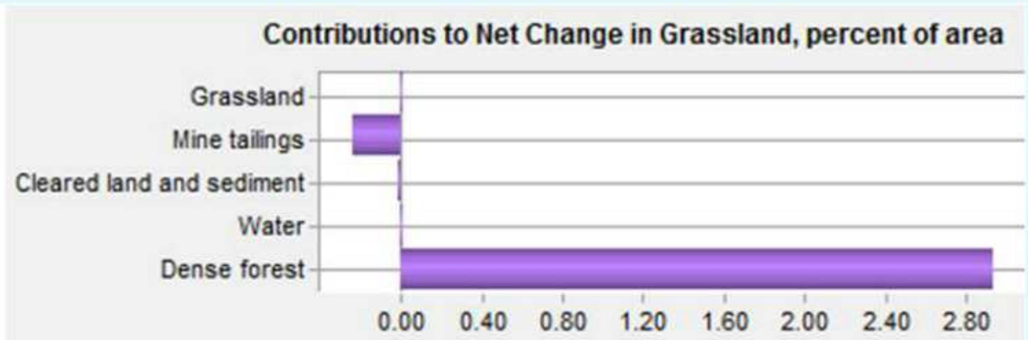


Figure 6: Contributions to net changes in categories of grassland, mine tailings, and cleared land and sediment in percent of total study area from 1986 to 1996 (left); 1996 to 2006 (center); and 2006 to 2011 (right).

Throughout the 25-years period dense forest areas contributed to an increase in grassland (44.35%), mine tailings (38%) and cleared land and sediment (17.65%).



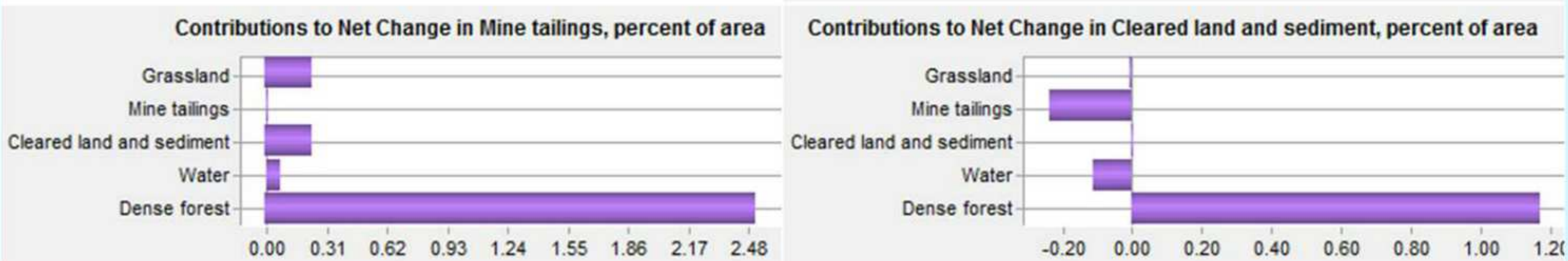


Figure 7: Contributions to net changes in categories of grassland, mine tailings, and cleared land and sediments in percent of total study area.

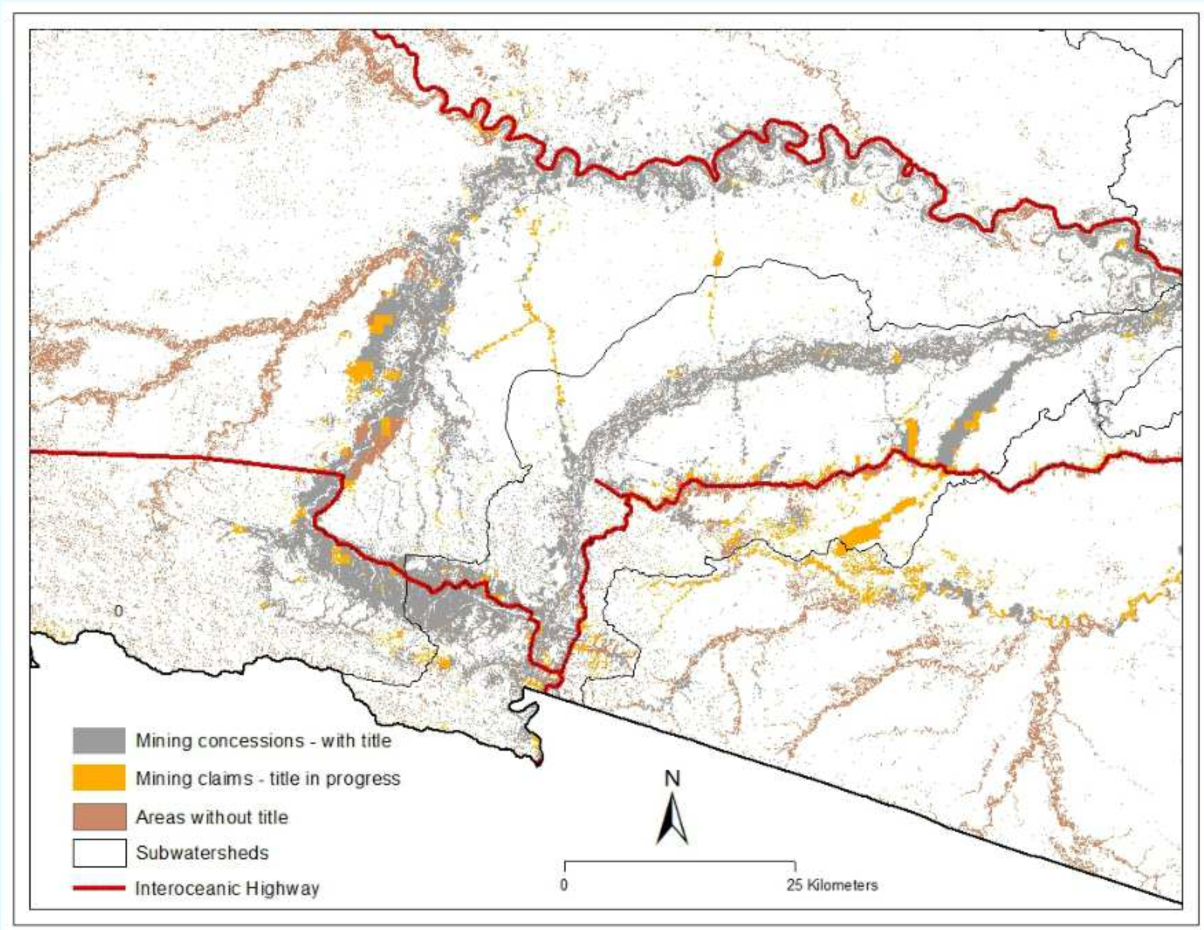


Figure 8: Map representing cumulative change between 1986 and 2011 in different ASM locations.

- Cumulative land cover change resulting from artisanal and small-scale gold mining operations occurred in ~1430.43 km^2 (~14% of the total study area).
- Mining concessions: 53.4%
- Mining claims: 12.6%
- Areas without title: 34%

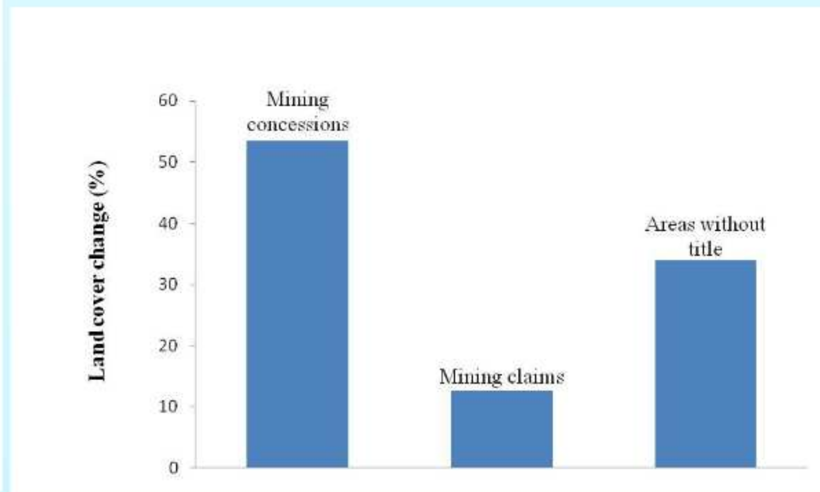


Figure 9: Proportion of change caused by ASM.

Conclusions

- Each classified map has approximately 13 m of inherent positional error associated with the study based on the relationship between the smallest object being mapped, tree crown (~17 m) in areas of intermediate dry season length (1 – 3 months), and the spatial resolution of the Landsat-5 imagery (30 m).
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Future Work and Improvements

- Use of decision tree classifier in order to directly incorporate other landscape variables such as topography, hydrology, higher resolution land cover maps, which ought to improve the accuracy of the classification.
- Higher resolution imagery and extensive field validations would be useful to map department-wide mining activity and discriminate the spectral signatures of mining sites from migrating rivers or mine tailings.

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Questions?

Thank you!