Ridge to Reef

Land Use, Sedimentation, and Marine Resource Vulnerability in Raja Ampat, Indonesia

Group Project Brief - Spring 2013

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Client: Conservation International

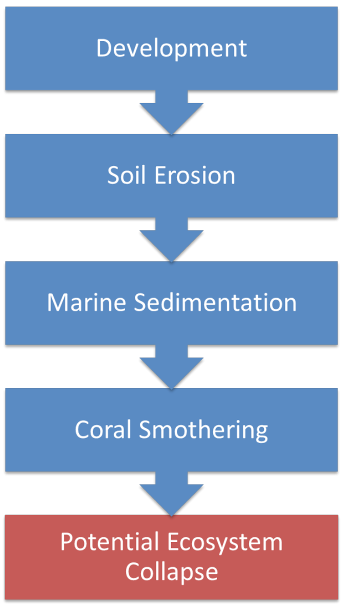
Photograph courtesy of James Morgan

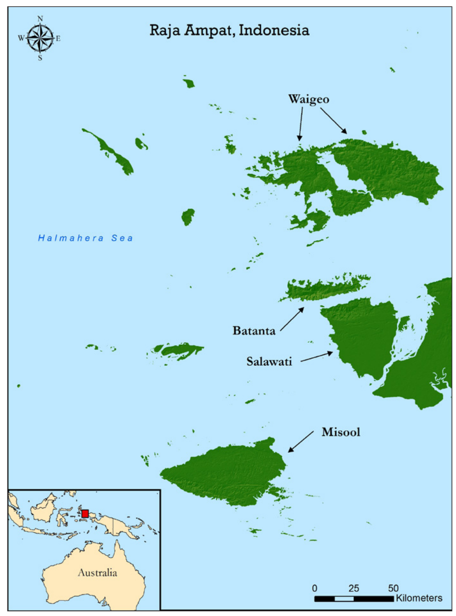
Introduction

Located in Indonesia's Western Papua Province, Raja Ampat is made up of four large islands and hundreds of smaller islands. Encompassing over 43,000 square kilometers (km^2) of land and sea, Raja Ampat contains 75% of the world's hard coral species and more than 1,300 coral fish species, making it a global biodiversity hotspot and conservation priority.[1,2] However, Raja Ampat is also rich in extractable resources, such as nickel, copper, oil, and hardwoods. As such, the region faces increasing population and development pressure, leading to land use change and soil erosion. Land uses, such as mining, agriculture, urban development, logging, and roads can alter soil erosion rates. This sediment is then washed into rivers with rainfall and enters the ocean. Sediments settle on coral and smother them by blocking sunlight and interfering with their ability to feed and disperse larvae. This can lead to ecosystem collapse across regions, which is especially significant for Raja Ampat due to its economic reliance upon marine resources. The majority of people in Raja Ampat depend on marine resources for food and income. Pearl farms, fisheries, and eco-tourism account for more than 80% of the region's total economy.[3]

Land use change can increase soil loss to the ocean, which smothers corals and can lead to large-scale ecosystem collapse.

Understanding the connection between development and ocean ecosystems is crucial for land use planning in Raja Ampat.





Problem Statement

Raja Ampat faces complex environmental, economic, and social challenges, but critical information gaps exist. Conservation International has asked us to take the first step in assessing how changes on land will impact resources in the ocean.

Our project specifically assesses the vulnerability of coral reefs, dive sites, pearl farms, and marine protected areas (MPAs) to sedimentation caused by land use changes by identifying:
(1) the terrestrial areas that have the highest potential for soil erosion,
(2) the marine habitat at risk to sedimentation, and
(3) how expected land use changes will influence soil erosion rates.

Methods

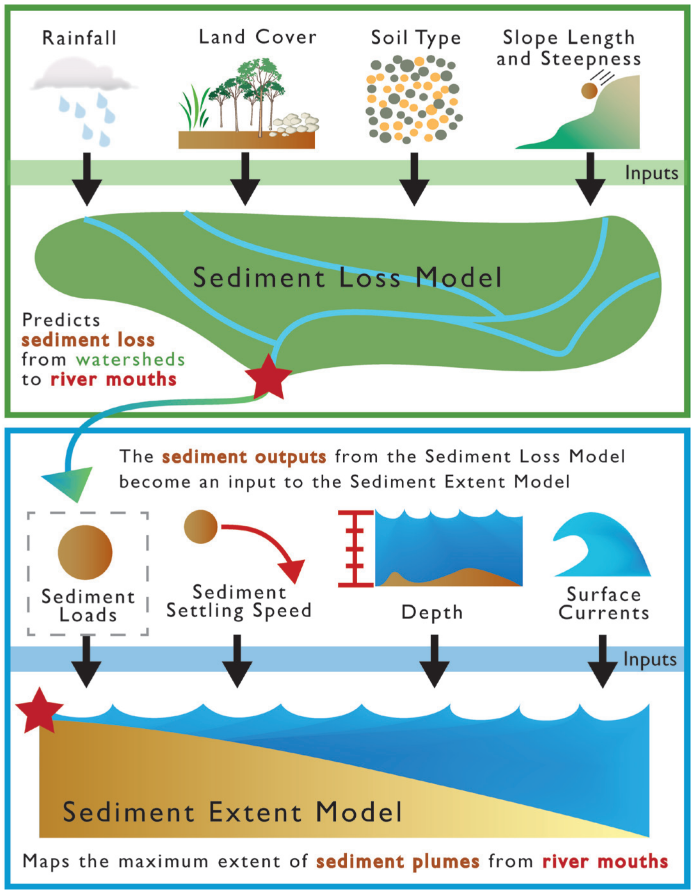
To address our research objectives, we developed a coupled terrestrial and marine model that quantitatively predicts the amount of sediment leaving each river mouth, and spatially models and displays where that sediment is dispersed once it enters the ocean.

Coupled Land-Sea Model

The terrestrial Sediment Loss Model implements a Revised Universal Soil Loss Equation (RUSLE) within a geographic information system (GIS). The inputs impact soil loss in a variety of ways. Rainfall acts a soil detachment and transport mechanism. Land cover reflects how much soil is exposed to rainfall and thus erosion. Different soil types erode more readily than others; for example, silty soils are more easily eroded than sandy soils. Soils on longer and steeper slopes are easily eroded. Sediment loads were calculated on a per-cell basis and can be aggregated to watersheds. To connect with the marine model, we routed sediment loads to each river mouth.

The marine Sediment Extent Model predicts how the sediment loads output from from the terrestrial model will be dispersed once they enter the ocean. This GIS-based model uses surface currents to drive horizontal movement, a sediment settling speed modified to compensate for near-shore processes, and ocean depth to calculate the maximum extent sediment could travel from any given river mouth.

For this study, we used readily-available global datasets to derive these parameters, including a digital elevation model (DEM), precipitation, soils, bathymetry, surface current data, and coral reefs. Other marine resource locations, including MPAs, dive sites, and pearl farms, were provided by Conservation International.



Utility of the Tool and Land Use Change Scenarios

All of the input parameters are user-specified and adjustable in terms of spatial and temporal scale. This makes the model a flexible tool that can be used in any location and for any time period and scale.

We demonstrated the utility of this tool by modeling two example land use change scenarios, conservative and intensive, to compare to current land use. These scenarios were developed using regional planning documents and in consultation with locals experts. However, they are not meant to predict future changes, but rather to showcase the ability of the terrestrial model to predict soil loss under variable land coverage.

Conservative Land Use Change Scenario

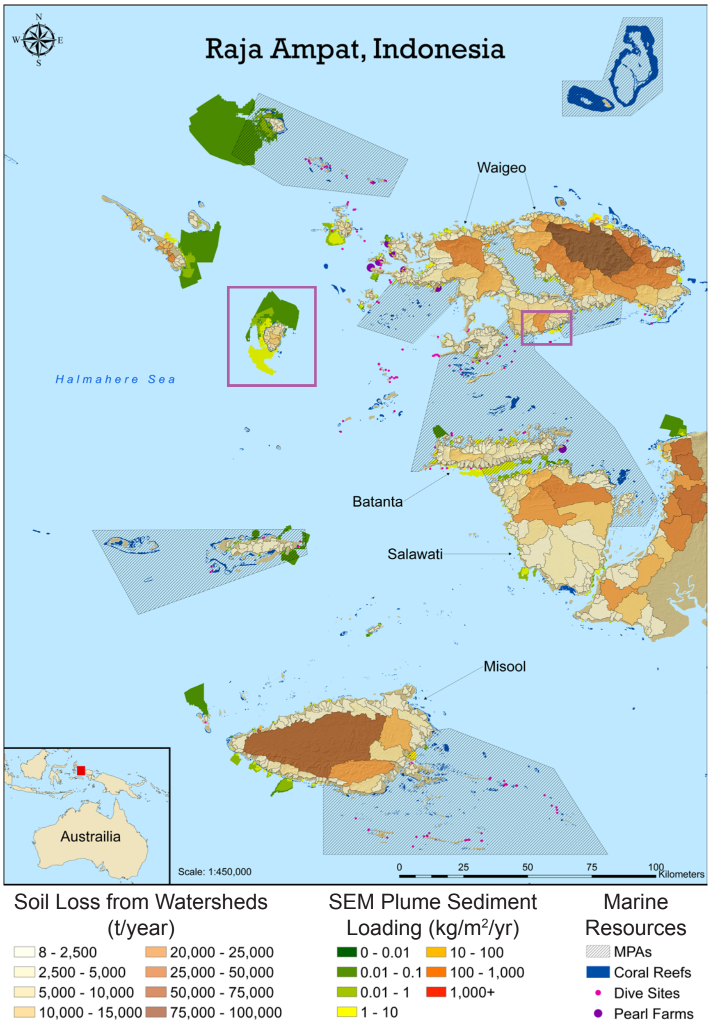
The conservative land use change scenario models urban growth, agricultural development, and mining activities on slopes primarily less than 20 degrees. Slope is usually a constraint on human development and people typically prefer to live, farm, and work on relatively flat land.

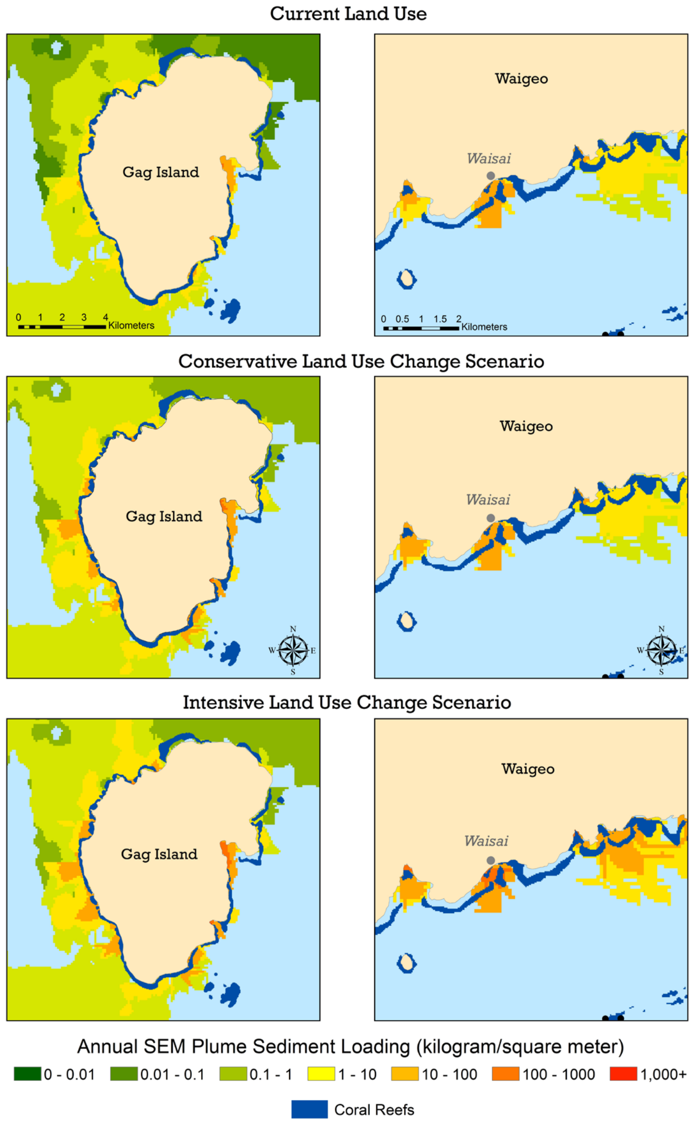
Intensive Land Use Change Scenario

The intensive land use change scenario models similar, yet slightly exaggerated development patterns in areas regardless of slope. Much of Raja Ampat is steep, and future population pressures may force people up-slope.

Model Output

The output (left) is a map showing (1) soil loss per watershed and (2) the maximum sediment extent plumes originating from each river mouth. The colors on land indicate the total soil loss from each watershed for the year 2011 under current land use. The colors within the plumes indicate sediment loadings, or total sediment averaged over the entire plume area. For this study, we ran the model for each month in 2011, and then summed the monthly sediment loads to show annual sediment loadings within plumes.





Left: Large output map under current land use showing annual soil loss per watershed and annual plume extents and sediment loadings for 2011. *Right:* Enlarged views of areas showing increasing sediment loadings on coral reefs between each land use scenario.

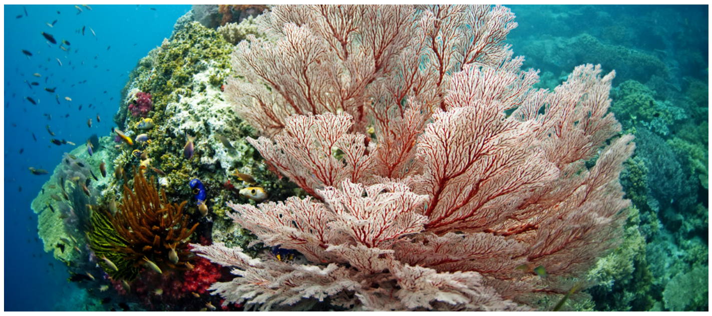
Under current land use (left), watersheds that are large or contain mines, roads, or steep slopes output the most sediment. The largest sediment extent plumes are located in the northwest part of the region, which is characterized by fast surface currents and deep water. Because these plumes are large, sediment loads within them are relatively low (dark green color). Along the northeast coast of Waigeo, shallow water and weak currents create small plumes. However, sediment loadings within these plumes are large, so these plumes pose a high sediment risk to nearby or overlapping marine resources. By varying the land cover parameter within the terrestrial model, we can compare changes in plume sediment loadings across scenarios (right). Increases in mining activities under the two example scenarios on Gag Island produce higher sediment loading, shown in the expanding orange plumes. Near the town of Waisai on southern Waigeo, increases in urban development and roads result in higher sediment loading, shown in the expanding orange plumes. Under the intensive scenario, more coral reefs are intersected by these plumes with high sediment loadings.

Vulnerable Marine Resources

We overlapped the locations of known marine resources in Raja Ampat with our sediment plumes to quantify the amount of these resources that are directly impacted by sedimentation.

Marine Resources Within SEM Risk Zones	Area or Count
Mapped Coral Reefs	57 km^2
MPAs	479 km^2
Dive Sites	4
Pearl Farms	1
Other Benthic Habitats	1,930 km^2
Area of ROI	43,000 km^2
Total Area of SEM Risk Zones	1,987 km^2

Sedimentation will directly impact almost 2,000 km^2 of marine habitat in Raja Ampat. These marine resources are significant for their contributions to global biodiversity and the regional economy.



Photographs courtesy of James Morgan

Conclusions

We developed a coupled terrestrial and marine model to assess how land use changes impact the amount of sediment entering the ocean, determine where that sediment is dispersed and quantify the vulnerability of marine resources to sedimentation. The tool is flexible in terms of spatial and temporal extent and can be applied to a variety of other planning processes and locations. Our tool can be refined with improved local data, including more accurate land cover (and predicted land use change), as well as fine-scale oceanographic characteristics.

The model can be improved with either high resolution current data or modified capabilities to better capture long-shore current movement. Land use planning efforts should consider important economic and biological effects along with sedimentation impacts. We recommend further research on the biological and economic linkages between sedimentation and key marine resources to provide a more comprehensive understanding of how land use change impacts the marine environment for land use planners and other stakeholders.

Photograph courtesy of James Morgan

Acknowledgements

External Advisors: James Frew, Sarah Lester
Conservation International: Christine Huffard, Hedley Grantham, Ismu Hidayat
Consultants: Libe Washburn, Benjamin Halpern, Eric Treml, Alex Messina, Alex Valencourt, Chuck Schonder, Eric Fournier, and Aubrey Dugger

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