Reefs at Risk in the Caribbean

Threats to coral reefs from land-based sources of pollution

Coral reefs support many economic activities and livelihoods. They provide habitat for fish and shellfish fisheries, a valuable source of protein and livelihood for many coastal communities. Coral reefs are an important attraction for tourists, supporting the lucrative dive tourism industry, and enhance coastal tourism in general through allowing the development and existence of white sand beaches. Coral reefs, and associated mangrove and seagrass ecosystems, protect shorelines, by reducing storm impact and routine erosion from waves. In addition, the profound biodiversity of these ecosystems has enormous value as a potential provider of life-saving pharmaceuticals, and for their pure aesthetic and spiritual value.

However, rising population densities, associated coastal development, and increased fishing, agricultural, and industrial activities are resulting in increased pressure on Caribbean coral reefs. The extent and degree of stress has increased markedly in the last 30 years and a wide range of human activities directly threaten coral reefs, resulting in degradation in many areas. Although pressure on coral reefs will increase as population grows and development increases, better management of development can help reduce the threat and protect these valuable ecosystems. As an aid to better management, the Reefs at Risk model produces map-based indicators, which are a simplification of human activities and complex natural processes, to gauge potential human pressure on coral reefs. Here, we present an overview of the indicators for land-based sources of threat to reefs.

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WATERSHED-BASED SOURCES OF SEDIMENT AND POLLUTION

Stormwater runoff and erosion are natural environmental processes. However, human activities that alter the landscape can increase both runoff and erosion, and ultimately result in increased delivery of sediment and pollutants to coastal ecosystems far removed from the converted lands. Conversion of land from forest and other natural land cover types to agriculture typically increases runoff (due to decreased infiltration), and exposes more soil to erosion. The runoff from lands converted to agricultural usage will also transport other pollutants, such as excess nutrients (especially nitrogen and phosphorus) from fertilizers, and toxic compounds found in herbicides and pesticides. In addition, conversion of land to urban or industrial use (urbanization), which is widespread in the region, results in increased river-borne pollution from industrial and domestic waste with significant negative impacts on coral reef ecosystems.

The effects of land use change are also exacerbated by natural disturbances, such as hurricanes. Altered land use compounded the effects of Hurricane Mitch in 1998 causing massive loads of sediment-laden water to flow out on to the Mesoamerican Barrier Reef System (MBRS).

PHOTO: LAURETTA BURKE

Pollution and erosion from land-clearing activities far inland contribute to reef sedimentation

THE IMPACTS

PHOTO: © WOLCOTT HENRY, 2001

SEDIMENT Increased sediment delivery to coastal waters is a key stress on coastal ecosystems. Increased sedimentation can cause a variety of negative impacts on coral reefs, including screening out light needed for photosynthesis, scouring of coral by sand and sediments, poor survival of juvenile coral due to loss of suitable substrate, and the direct smothering of coral in cases of extreme sedimentation.

NUTRIENTS Elevated nutrient in coastal waters promotes increased algal growth on coral reefs, and can result in algal blooms, changes in the aquatic community structure, decreased biological diversity, and fish kills.

TOXIC SUBSTANCES Heavy metals, petroleum hydrocarbons (much of which comes from runoff of motor oil and other wastes from roads), and other toxic materials are a cause for concern because of their poisonous effects on aquatic life, and because their accumulation in the tissues of fish and shellfish can be harmful to human health.

Analysis Approach

Watersheds are critical units for analysis since they link land areas with their point of discharge to the sea. A watershed is the area of land that drains water, sediment and other pollutants to a common outlet along the coastline. In this analysis we try to capture the influence of the primary factors that affect erosion: land cover type, slope, soil characteristics, and precipitation. These relative erosion estimates are summarized by watershed. As not all erosion makes its way to the river mouth, sediment delivery ratios (based on watershed size) were applied in order to estimate relative sediment delivery at the river mouth. Sediment plumes were estimated based on the relative sediment delivery and distance from each river mouth. By overlaying sediment plumes with the location of coral reefs, we are able to estimate the degree of threat to coral reefs from watershed-based sediment and pollution. (See map below.)

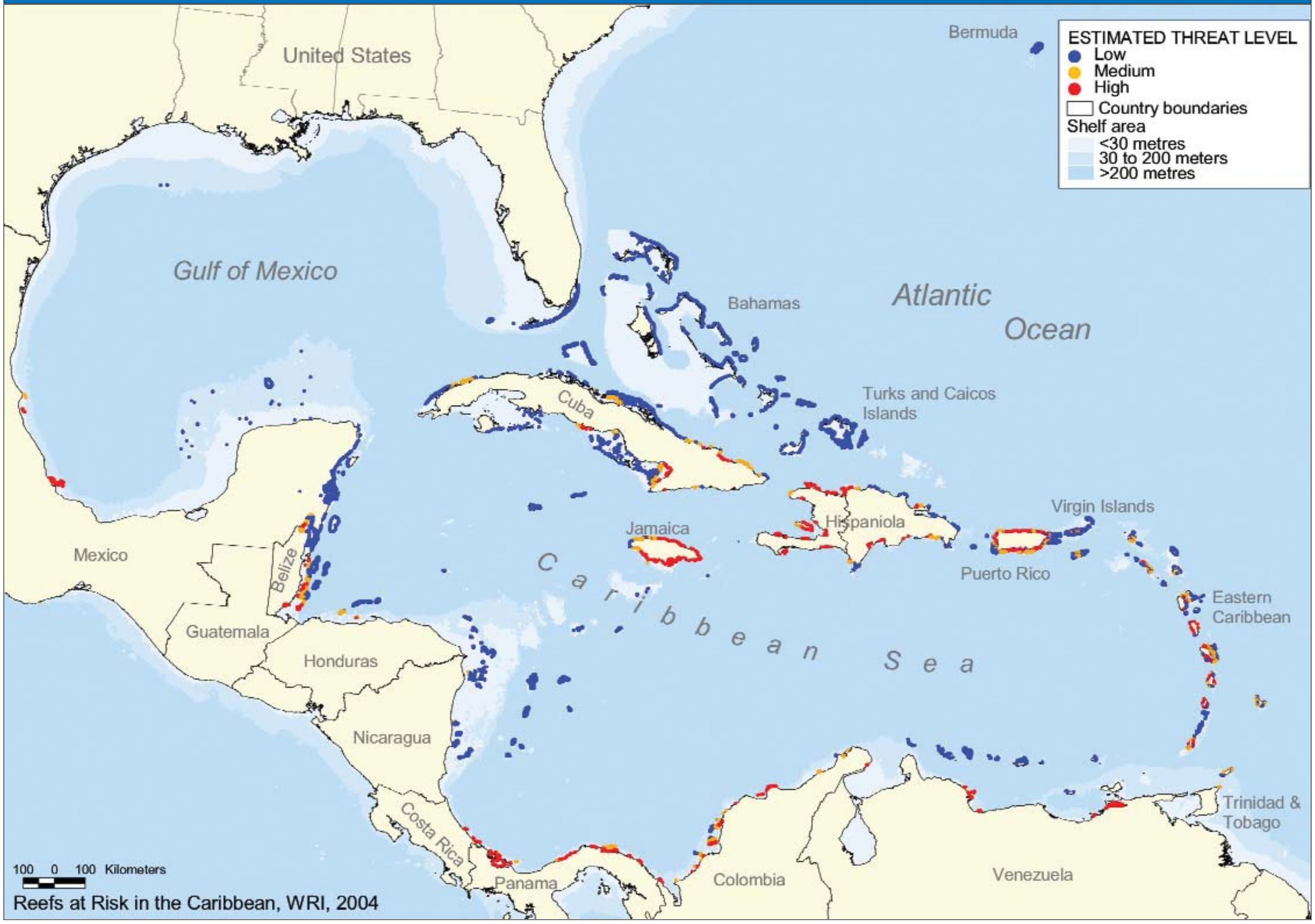
The value of this approach

This approach permits patterns of land use within watersheds to be linked with sources of sediment transport and delivery to coral reefs, enabling those reefs at greatest risk to be identified. Maintaining healthy coral reef ecosystems and their associated biodiversity depends on applying appropriate land-use practices in critical watersheds to ensure that the impact of sediment, nutrients, and other pollutants on the coral reef system is minimized. Using this approach, it is possible to identify those areas that will be particularly sensitive to development or land use changes, and facilitate the prioritization of watersheds to ensure that the best practices are developed in areas where land use change is most threatening to the health of coral reefs.

LANDSAT IMAGE COURTESY OF NOAA

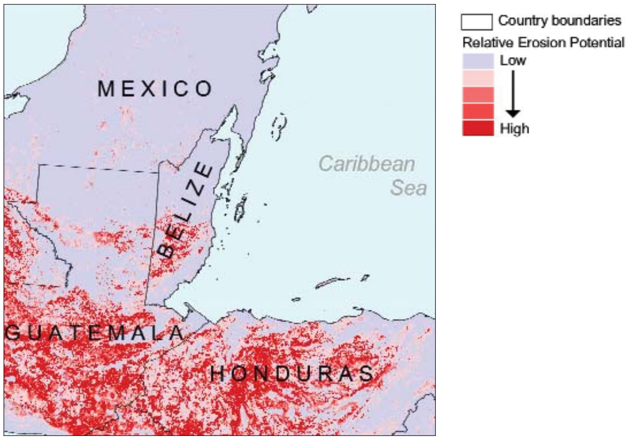
This Landsat image of the northwest of Puerto Rico, taken in January 2003, clearly shows sediment laden plumes dispersing along the coast.

REEFS THREATENED BY WATER-BASED SOURCES OF SEDIMENT AND POLLUTION



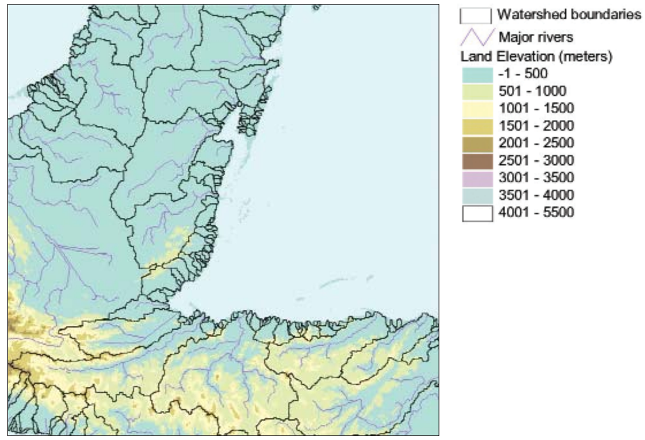
Threat from watershed-based sources was identified as particularly high in the Southwestern Caribbean, in the Bay of Honduras, and off many of the high islands in the Greater and Lesser Antilles.

Model Implementation



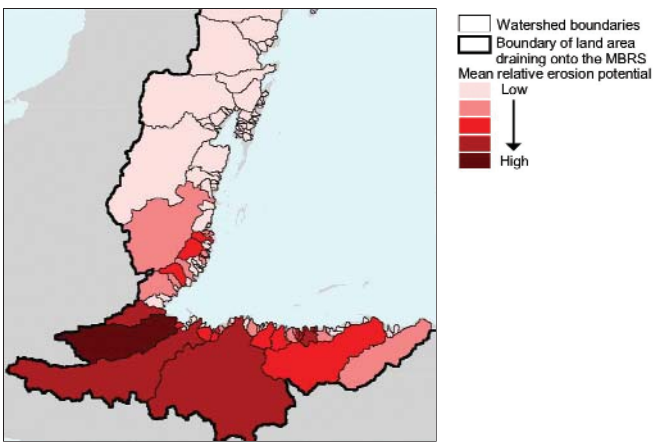
1. DERIVE RELATIVE EROSION POTENTIAL

We use a simplified version of the Revised Universal Soil Loss Equation (RUSLE)[1] in order to estimate likely erosion rates for each 1 kilometer resolution grid cell. Information on slope, land cover type, precipitation, and soil porosity were integrated to develop an indicator of relative erosion potential (REP) for all land areas within the wider Caribbean.



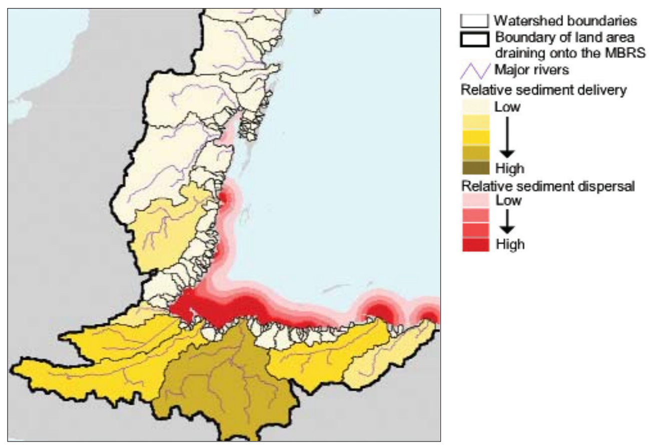
2. DELINEATE WATERSHED BOUNDARIES

Watershed boundaries were developed for the region based on a 1 kilometer resolution elevation data set (DEM).[2] At WRI the DEM was "filled" and rivers and lakes were "burned" to improve the accuracy of the watersheds. This resulted in a data set of more than 2,700 watersheds draining into the Caribbean, with a minimum size of 35 km^2.



3. CALCULATE EROSION INDICATORS BY WATERSHED

Two indicators of erosion for the watershed were calculated for each watershed — mean relative erosion potential within the basin and total relative erosion potential for the basin. This map shows which watersheds have the highest mean erosion rates.



4. CALCULATE SEDIMENT DELIVERY AT RIVER MOUTH AND DISPERSE SEDIMENT

An indicator of relative sediment delivery at the river mouth was estimated by multiplying total relative potential erosion in the basin by the sediment delivery ratio for the basin, which is a function of watershed size.[3] We estimated relative sediment plumes by dispersing sediment delivery from the river mouth using a distance-based decay function.[4]

Notes

1 USDA. 1997. Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). USDA Handbook 703.

2 US Geological Survey HYDRO1K Digital Elevation Data Set (DEM), 2000

3 Sediment Delivery Ration (SDR) = 0.41 * basin area (in sq.km) $^{-0.3}$ (This factor comes from Thattai, D., B. Kjerfve, and W. D. Heyman. 2003. Hydrometeorology and variability of water discharge and sediment load in the inner Gulf of Honduras, Western Caribbean. *Journal of Hydrometeorology* 4(6):985-995.)

4 The plume function used a 10% reduction in sediment per km from the river mouth; Model results were calibrated based on available data on river discharge, sediment delivery, and observed impacts to coral reefs. It should be noted that relative erosion rates and sediment delivery are being used as a proxy for both sediment and pollution delivery.

COASTAL DEVELOPMENT

PHOTO: © WOLCOTT HENRY, 2001

The growing population and expanding tourism in the region drive the demand for the construction of new infrastructure in the coastal zone. Coastal development can result in direct or indirect pressures on coral reefs from construction, sewage discharge and poorly managed tourism.

In the analysis, we developed an indicator of coastal development threat which incorporates estimated pressure from sewage discharge, urban runoff, construction, and tourism development. Threats to reefs were evaluated based on distance to cities, ports, airports, and tourism centers. In addition, "coastal population pressure" was included in the analysis, as a function of coastal population density, coastal population growth, per capita GDP, and annual tourism growth.

THE IMPACTS

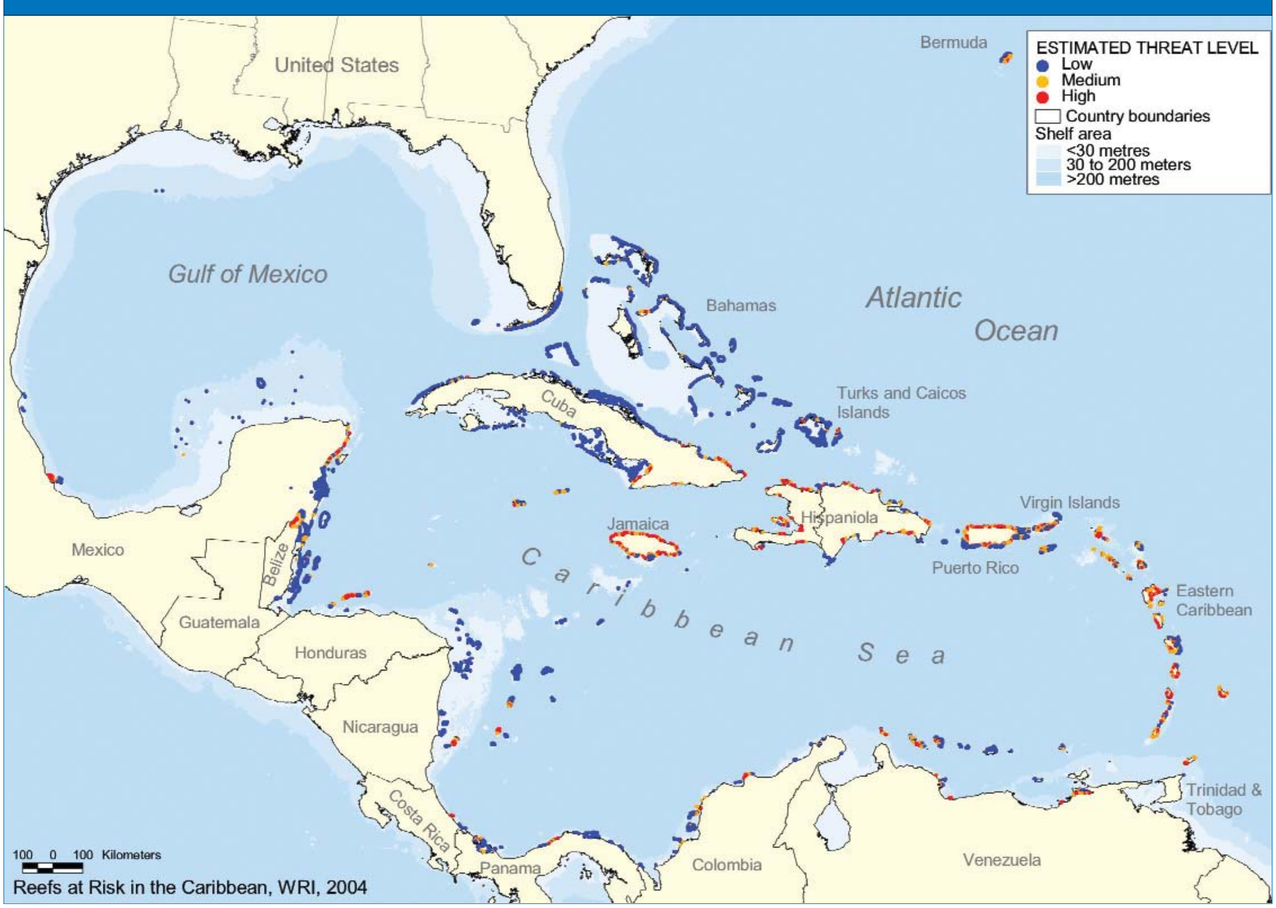
PHOTO: © WOLCOTT HENRY, 2001

BACTERIA Untreated sewage can contains bacteria and other harmful pathogenic organisms, which contaminates fish and shellfish and also detrimentally affects water quality for recreational users.

NUTRIENTS The widespread discharge of untreated sewage is a major source of nutrients entering coastal waters. Elevated nutrients in coastal waters promote increased algal growth on coral reefs, and can result in algal blooms, changes in the aquatic community structure, decreased biological diversity, and fish kills.

PHYSICAL IMPACT Coral reefs can be obliterated through the removal of coral substrate, or by burying the reef under sediment.

REEFS THREATENED BY COASTAL DEVELOPMENT



Threat from coastal development is significant in most of the Lesser and Greater Antilles, along parts of the Yucatan, the Bay islands, and along parts of Colombia's and Venezuela's coasts.

ACTIONS NEEDED

A wide range of actions at the local, national, and international levels are needed to mitigate the wide range of threats to coral reefs from human activities and environmental conditions. Fundamental to these actions are a better understanding of the economic value of goods and services derived from coastal ecosystems and of the linkages between human activities and changes in coral reef condition.

1. Promote better agricultural planning and management to minimize sediment and pollutant delivery to coastal waters.
2. Expand and improve levels of sewage treatment to reduce harmful pollutant discharge to coastal waters.
3. Improve information on environmental conditions in coastal waters and information on treatment levels of sewage and industrial waste and make that information feely available.
4. Promote Integrated Coastal Management. Successful management of coral reefs requires a broad approach that is ecosystem-based, so that approaches to conserve coral reefs are comprehensive. Participation from a wide-range of stakeholders, including government, local communities, the private sector, and non-governmental organizations (NGOs), is critical.

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PHOTO: COREL PHOTO CD

WRI and the Reefs at Risk Project

In 1998, in response to the need for better information on the status of and threats to coral reefs, the World Resources Institute (WRI) released *Reefs at Risk: a map-based indicator of threats to coral reefs*, a detailed analysis of human pressure on coral reefs. This global analysis provided the basis for launching the Reefs at Risk project series. The primary goals of the series are to raise awareness about threats to coral reefs and to make available a comprehensive, high quality base of information on a regional level, as an aid to more effective management. In March 2002, *Reefs at Risk in Southeast Asia* was published and the second study in this series, *Reefs at Risk in the Caribbean*, will be released in the fall of 2004.

For More Information

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PROJECT PARTNERS

Partnership is essential to the Reefs at Risk project success. Partners provide data, review the analytical approach and results, and guide outreach.

- Atlantic and Gulf Rapid Reef Assessment (AGRRA)
- Caribbean Conservation Association (CCA)
- Caribbean Coastal Marine Productivity Program (CARICOMP)
- Coral Resource Management
- CORALINA
- Environmental Defense
- Florida International University
- Global Coral Reef Monitoring Network (GCRMN)
- Island Resources Foundation (IRF)
- National Center for Caribbean Coral Reef Research (NCORE)
- The Nature Conservancy (TNC)
- Reef Check
- United Nations Environment Programme's Caribbean Environment Programme (UNEP-CEP)
- UNEP–World Conservation Monitoring Centre (UNEP-WCMC)
- U.S. National Aeronautics and Space Administration (NASA)
- U.S. National Oceanographic and Atmospheric Administration (NOAA)
- University of Miami
- University of South Florida
- University of the West Indies (UWI)
- World Bank / GEF Mesoamerican Barrier Reef System Project
- The World Fish Center
- World Wildlife Fund (WWF)