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Cattle, crops, and coral: Flood plumes and the Great Barrier Reef [1]

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Understanding river runoff will help solidify the link between land use and coral health.

- About the data used
- About NASA Goddard Space Flight Center Earth Sciences Data and Information Services Center (GES DISC) [2]

Most of the time, Australia's Fitzroy River does not really exist. For years at a time, the river is only a dry streambed. Upriver, cattle wander about the surrounding rangeland, plucking at tufts of brown grass and kicking up dust. Downriver, farmers irrigate, fertilize, and tend their cotton and other crops. Every five or ten years, the rains come. In a single day, water can pour down the river at a rate of 1.5 cubic kilometers (0.4 cubic miles) per second from a river catchment the size of the state of Illinois. The Fitzroy's waters flush sediment, fertilizers, pesticides, herbicides, and other civilization-borne runoff hundreds of miles into the water off the coast of Australia. At the end of the runoff plume, waiting for the sediment and nutrients to settle, are the prismatic corals of the Great Barrier Reef. The Great Barrier Reef is the world's largest marine ecosystem and an economic bedrock for Eastern Australia. When the Fitzroy's runoff arrives at the coast, where exactly does it go, what does it do to the Great Barrier Reef, and what can be done about it?

Feedback

Tracking the runoff

Arnold Dekker is a scientist with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Dekker is collaborating with researchers from the Australian Institute for Marine Science and James Cook University to study river runoff into the Great Barrier Reef Lagoon, the body of water between the coast and the Great Barrier Reef. Dekker said, "We can see huge sediment plumes at the mouth of the rivers as the water sweeps sediment into the Great Barrier Reef Lagoon after extreme rain events. We wondered: Can we track plumes of water? Can we trace the influence of land runoff?" The questions have not been easy to answer.

"Australia is a data-poor environment. It's a huge continent—the coastline along the Great Barrier Reef, alone, is thousands of kilometers long," Dekker said. "We know very little about how the rivers and coasts and oceans actually interact." Besides the immense length of the coast that bounds the Great Barrier Reef, an additional challenge is that flood events are infrequent and ephemeral. "Field measurement programs are weather-dependent and crews can only go out about once a month; they can't really establish long-term patterns very well," Dekker said. "But satellite imagery can give a much more holistic view of the materials that the river is transporting and where they are going, as well as nutrients that may cause algal overgrowth." Plus, satellites can capture information about flood plumes through actual images from space, which would be difficult or impossible to accomplish using traditional observation techniques.

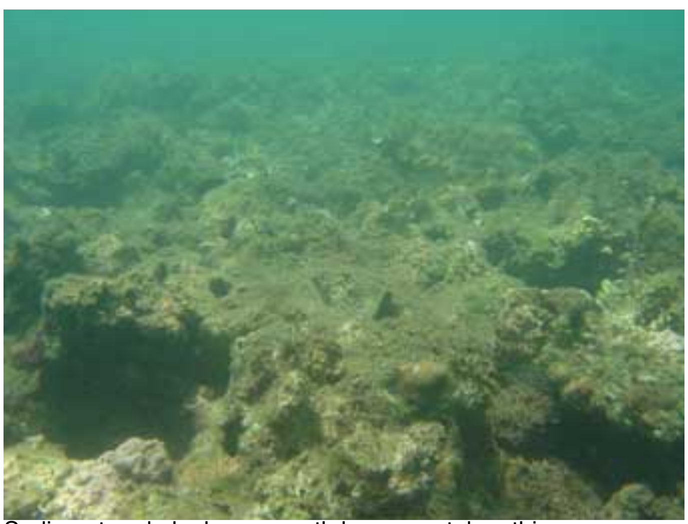
A diversity of colorful fish and marine species live in the clear waters near this healthy reef. (Image above and in title graphic courtesy Emre Turak/Australian Institute of Marine Science)

Scientist Jon Brodie, of the Australian Centre for Tropical Freshwater Research (ACTFR) at James Cook University, agreed. "I've been trying to track flood plumes for twenty years, and now we finally have enough satellites up there that we have daily overpasses. Even in cloudy weather, we can get images every day," he said. "For example, after years of effort, last year we got clear images of Pioneer and O'Connell river flood plumes—every day for ten days."

Dekker is primarily using ocean color data, archived at the NASA Goddard Space Flight Center Earth Sciences Data and Information Services Center (GES DISC), from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the NASA satellites Aqua and Terra. Dekker uses the ocean color data to track differences in the color of the coastal water following flood events. Coastal waters are notoriously difficult to work with, and Dekker's team had to develop algorithms, or complex processing equations, to better make use of the data. "Unlike in clear ocean water, coastal optics are dominated by more than just green chlorophyll. There's also colored dissolved organic matter—the stuff called tannins that colors water pea soup green, yellow, brown, or orange," Dekker said. "Plus, you have suspended matter, re-suspended matter, bottom visibility—and ships, tides, and cyclones churning it all up."

Dekker and his team are applying the new algorithms in three areas of study: using MODIS data archives to determine long-term trends in nutrient increases and algal blooms along the entire Eastern Australian coast; providing near-real-time images to coastal managers; and performing focused research on specific coastal regions and systems.

Determining long-term trends in water quality will require Dekker to go back into the MODIS data archives to reconstruct and quantify amounts of sediments and chlorophyll. Chlorophyll, while not a direct measure of nutrients, often indicates the presence of nutrients. Dekker said, "Chlorophyll and other algal pigments, colored dissolved organic matter, and suspended matter all color the water and combine to give a pretty strong argument for nutrient enrichment."



Sediment and algal overgrowth have overtaken this once-healthy reef. (Courtesy Emre Turak/Australian Institute of Marine Science)

Understanding such trends as river outflow, algal blooms, and eutrophication—or increasing levels of nutrients and minerals that stimulate plant growth—is important for monitoring Australia's coastal waters. Andy Steven, a former Environmental Protection Agency catchment scientist who currently works at CSIRO, said, "Remote sensing allows us to cover vast areas of the reef with frequent and consistent data. This allows us to set a line in the sand based on some measure of water quality, and then collect data to compare how we are doing." Coastal managers can then monitor ongoing water quality to determine whether things are improving, getting worse, or staying the same. "The only way that we can be responsible stewards of a great ecological asset like the Great

Barrier Reef is to have adequate monitoring programs telling us the true status of the system," Steven said. "And the only cost-effective and reliable tool that we can see is remote sensing."

However, effective use of remote sensing will not only start with scientists. Steven said, "Getting the trust of coastal managers is one of the broad goals that we'll need to crack in the next four to five years." One way that Dekker hopes to raise their trust in remote sensing is to provide near-real-time satellite images that will help managers make decisions based on current, reliable information. Dekker said, "We'll probably provide the images through a Web-based system so that they can see what's going on in their system, in their estuary, or along their coast." The key, Dekker said, is to meet the real needs of the managers on the ground. "They've got so little information on what's going on; a series of images would give them the insight they need into where material is going," Dekker said. "The next stage of that project could be a harmful algal bloom warning system."

Steven explained that the algal bloom warning system would probably be based on a blend of different types of information, such as chlorophyll, suspended sediment, and wind data that would create flags in the data under certain circumstances. "Then you might send a message to the relevant coastal managers that they need to be aware of a developing situation," Steven said. "Together with information on local conditions, the managers could make proactive decisions based on real-time data." For example, if coastal managers received a forecast that conditions could lead to a potential harmful algal bloom, they could issue a warning that the water may be unsafe for swimming.

Perhaps the project that has yielded the most results, so far, is Dekker's focused research on the interaction between the Fitzroy River and the waters of the Great Barrier Reef Lagoon. Dekker said, "We've got all these models that show what the Fitzroy waters do. For example, we have a hydrodynamic model that shows beautiful animated loops of how the waters go in and out of the estuary with the tides, altering the distribution of suspended materials. But we're noticing that, while sometimes the MODIS data shows similar patterns of suspended sediment, chlorophyll, and algae, at other times it's showing different patterns. The MODIS data is beginning to drive the field of modeling, in turn helping us understand how estuaries and the Fitzroy outflow interacts with the Great Barrier Reef."

By studying and analyzing four years of MODIS data for the Fitzroy River, Dekker also discovered an important piece of information concerning the direction and distance of river outflow. "Most of the material goes to the east, straight out from the river, with some transport along the coast to the north and even less to the south," he said. This information has helped coastal managers understand which areas of the Great Barrier Reef the Fitzroy River floods affect, as well as how far into the reef the nutrient-laden waters spread. Steven said, "The Fitzroy is usually quite dry. So when the river flows, it really flows. And it has a significant and acute impact; it can virtually reset the whole ecosystem." In 1991, the Fitzroy River flooded spectacularly. "We recorded changes in suspended sediment and salinity up to Heron Island, which is about 120 kilometers (75 miles) off the coast," Steven said. "MODIS provides a great opportunity to capture what's going on there and how far it is going. If we can measure total suspended solids, we know how far they're spreading and what the likely area of risk is for the reef."

This MODIS image from July 19, 2006, shows muddy water from the rangeland-dominated Fitzroy River catchment entering the waters near the Great Barrier Reef, seen in turquoise off the East Coast of Australia. Information about flood plumes helps coastal managers understand which areas of the reef the floods affect, as well as how far into the reef the sediment- and nutrient-laden waters spread. White indicates cloud cover. (Courtesy Arnold Dekker/CSIRO)

Downriver realities

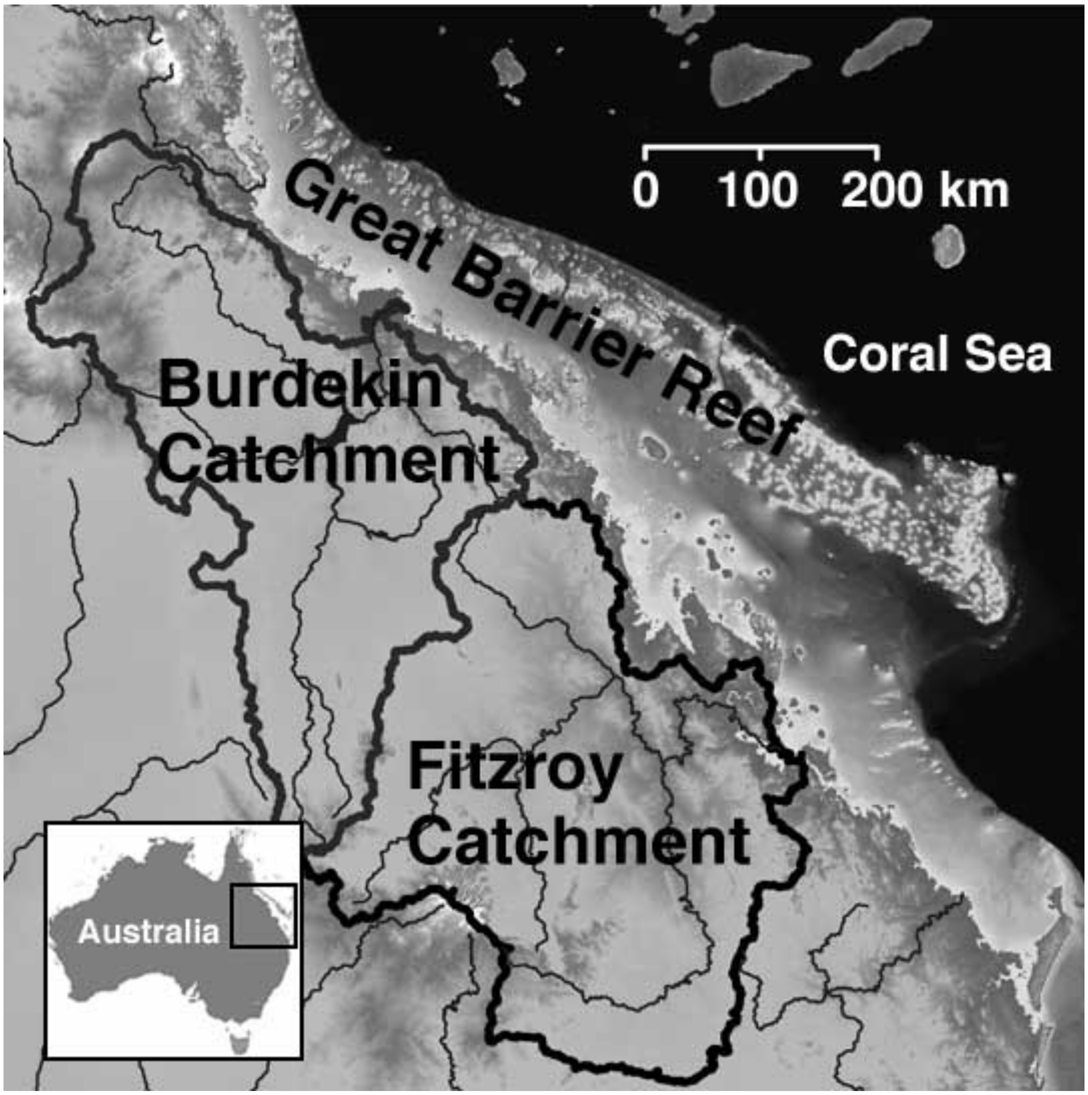
The Great Barrier Reef consists of three layers of reef: the inner reef, closest to the coast; the mid-reefs; and the outer reef, which is the furthest out to sea. Dekker said, "The inner reefs have always had to deal with more runoff from the land. So it's possible that the reefs closer to shore are more adapted to having increased suspended sediment and chlorophyll."

Brodie agreed, adding, "The suspended sediments don't travel very far; they stay near the coast. But nutrients like nitrate are not immediately taken up biologically and can travel much further than we would have thought, for hundreds of kilometers up the coast and across the reef under plume conditions. They present a risk to the offshore reef that we wouldn't have guessed at a couple of years ago."

What risks does runoff pose to the coral reefs? Reef-building corals are small animals living in reefs that they build through their secretions. However, corals respond to the world around them almost like plants because they have a symbiotic relationship with zooxanthellae, a type of algae that gives the transparent corals their vibrant colors. Zooxanthellae live in the coral's tissues and use light for photosynthesis; they assist corals with nutrient production and the calcification needed to build the protective reef. In return, corals provide the algae with carbon dioxide and protection from predators. The corals gain nutrients day and night, using photosynthesis during the day and living off other reef animals at night.

However, this tightly managed nutrient budget is susceptible to change, especially changes in temperature, light, salinity, or nutrient levels. Land runoff may affect all of these measurements, but is especially likely to change light and nutrient levels by adding nutrients that spur algal growth, and increasing turbidity. Dekker said, "A fear is that the resilience of the corals on the Great Barrier Reef decreases with increasing nutrients and suspended sediment. There is more smothering, less light availability, and you're upsetting some of the delicate balances in the reef." A recent study published in Ecology Letters indicates that algae release sugars that spur the growth of bacteria; the bacteria cut off oxygen to the corals, suffocating them and leading to further mortality. Turbidity, while perhaps not as directly linked to mortality as overabundant algae, can reduce the amount of light that gets to the corals, affecting photosynthesis.

The world's reefs face multiple pressures, in addition to land runoff. Brodie said, "When you have pressures like crown-of-thorn starfish outbreaks, cyclones, bleaching, climate change, sea water temperature rise, over fishing—the reason that our reefs look like they do is a complicated story." Piecing apart the various pressures and their impacts on the reefs is difficult, but the importance of clear, clean water should not be underestimated. "In good water quality conditions, the reefs can recover quite well from acute events," Brodie said. "But when you have other pressures plus poor water quality, the reefs don't recover."



The enormous catchments of the Burdekin and Fitzroy Rivers empty into the Great Barrier Reef Lagoon, affecting the health of Australia's world-famous reef. (Courtesy Peter Briggs/CSIRO; inset locator map © Commonwealth of Australia, Geoscience Australia, 2005)

Feedback

Upriver solutions

The plumes of runoff that Dekker helps track using MODIS are a good way to assess water quality on the Great Barrier Reef. However, water quality on the reef depends on conditions far inland, where the water begins flowing towards the coast. Brodie said, "If you want to do something about conditions at the mouth of the river, then there's no point doing anything on the Great Barrier Reef. You have to do it hundreds of kilometers upriver."

The two greatest inputs of sediment and nutrients into the Fitzroy River are cattle ranches and farms. "We have a whole raft of pollutants coming out of the catchment, including sediment and dissolved nutrients and herbicides," Brodie said. "Much of our work is aimed at disentangling those pollutants, identifying which industries are producing which ones and in what quantities. So we do a lot of monitoring to determine source areas."

Cattle grazing is a large source of sediment into the Fitzroy. Dekker said, "There's increasing evidence that in the past 200 years, since European settlement and changes in land use, there has been a significant increase in suspended sediment and nutrient input." As the cattle graze, they break down the riparian areas along the riverbanks, sending soil into the streambed to be carried away during the next flood. Unmanaged cattle will also spread out over the land, increasing erosion by stirring up the soil and grazing on the groundcover. Brodie said, "We believe sedimentary export has increased five or six times over natural erosion because of cattle grazing."

Several government programs, under the Department of Primary Industries and Fisheries, seek to help land managers and cattle ranchers connect. "We're using the Southern Oscillation Index, a measure of air pressure, to predict what the weather is going to be like next wet season. The idea is for ranchers to manage the cattle in advance. If it's going to be a bad drought year, you could sell off your cattle now," Brodie explained. "But if it's going to be a good year with lots of grass, then you might build your cattle numbers up a bit. That allows us to retain better pasture cover."

Another program subsidizes fencing so that farmers can confine cattle to specific areas of rangeland and move the animals from paddock to paddock. Controlling the cattle allows the vegetation to recover, protects riparian areas, and holds down erosion.

Nutrient input from farming also concerns scientists. Fertilizers contain large amounts of nitrate, which can leach into groundwater and river systems. Brodie indicated that nitrate discharge from rivers has increased ten to twenty times over natural amounts.

However, controlling nutrient input from farming is a bit more challenging than preventing overgrazing, Brodie said. "We have 7,000 individual sugar cane farmers and we can't monitor everywhere," he said. "We do have some simple monitoring that they can do themselves—thirty-cent test strips that measure nitrate flowing out of the fields." However, the most important aspect of farm runoff management is to influence the way farmers use fertilizer, before it gets into the water. "We can replant vegetation and artificial wetlands," he said, "but the best solution to fertilization loss is on the farm itself, rather than trying to trap it once it gets off. That, and choosing the right amount of fertilizer for the crop."

The challenge of improving water quality coming out of ranches and cropland goes beyond monitoring and subsidizing improvements. "Another problem is political expectations," Brodie said. "Government officials are spending millions on these water quality issues, and they want to see results immediately. But you can't plant seedlings along the river one year and expect them to be doing anything the next year. It takes ten years for them to grow big enough to trap sediment and nutrients."

Plus, the river's natural variability, flooding one year and then not flowing again for several years, makes getting statistically valid data a long-term project. "Picking a human signal out of that huge natural variability is very difficult," Brodie said.

Convincing government officials that land management efforts are making progress, even though the numbers are not final, is also an ongoing challenge. "What they have to take as evidence is on the ground: that we have an extra ten farms using the grazing land management package or that we've built all this fencing to manage the cattle," Brodie said. "And those improvements will produce—believe us, trust us—a change in the river."

And the scientists believe and trust that a change in the upper reaches of the Fitzroy River will trickle down to the Great Barrier Reef Lagoon, helping keep the water clear and clean for the health and survival of the corals of the Great Barrier Reef. With a healthy reef come billions of dollars of economic benefit for Australia, potential new medicines from coral substances, and the immeasurable beauty of a complex ecosystem thriving in the waters that have been its home for eighteen million years.

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Related Links

- NASA Goddard Space Flight Center Earth Sciences Data and Information Services Center (GES DISC) [5]
- Commonwealth Scientific and Industrial Research Organisation [6]
- Australian Centre for Tropical Freshwater Research at James Cook University [7]
- NASA Aqua satellite [8]
- Great Barrier Reef Marine Park Authority [9]

About the remote sensing data used	
Satellites	Aqua and Terra
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets	Ocean Color [10]
Resolution	1 kilometer
Tile size	Regional extract from granules
Parameter	Total suspended matter concentration in ocean Chlorophyll-a concentration, semi-analytic ("chlor a 3") Gelbstoff absorption coefficient at 400 nanometers
Data center	NASA Goddard Space Flight Center Earth Sciences Data and Information Services Center (GES DISC [2])
Science funding	Commonwealth Scientific and Industrial Research Organisation Cooperative Research Centre for the Reef

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