Volume 21 | Issue 10 | Page 46
Reprints | Issue Contents

1 comment
Comment on this article

Page Tools

By Andrea Gawrylewski

The city of Colón is a bustling and rapidly developing free-trade zone overlooking the Atlantic Ocean. Eighty kilometers north of Panama City, Colón was Panama's original shipping hub, the branching point of merchants and investors of the 16th century, hundreds of years before the construction of the Panama Canal (1904 to 1914). Colón sits at the mouth of the Chagres River, Panama's largest river along the Atlantic coast, and enjoys the warm salt air blowing from the Caribbean and twice the rainfall received by the Panama City coast.

Down a narrow paved road that branches away from Colón's massive Free Zone, black mangroves extend in every direction. Their roots, like stilts, seem to delicately pick at the still, dark brackish water. The forest opens up at the coast, where a squat blue building sits on a stretch of flat coral lapped by running waves. Once a former US Navy post that kept guard of the northern entrance to the canal, the base is now the Galeta marine lab, a Smithsonian Tropical

Research Institute (STRI) research base and educational center for visiting scientists and students.

The lush forest of the former Canal Zone - 1,432 square kilometers that extend eight kilometers from each bank of the canal - remained untouched for more than 85 years, until 1999, when the United States restored the management of the canal to the Republic of Panama. That move also opened up the zone to development and deforestation: The mangrove forests that once extended for 5,000 kilometers have already declined, and they continue to change at the hands of the expanding shipping industry. More than 14,000 ships already pass through the canal each year; many of them are the giant Panamax ships, 320 meters long and carrying as much as 65,000 tons of cargo.

The container industry has revolutionized shipping, especially at the northern mouth of the canal, where forest has been cleared to make room for cement container platforms, each about a meter thick. When the Republic of Panama finishes expanding the canal (projected completion in 2014) the waterway will be able to accommodate 425 meter long vessels capable of carrying up to 12,000 containers.

The expansion, however, will require clearance of some 7 square kilometers of forest. "There's a huge amount of deforestation and forest fragmentation," says STRI biologist William Laurence. "And this is the narrowest bottleneck in the meso-American corridor, a forest corridor. The most critical part is in central Panama and this area is getting hyperdeveloped because of canal expansion. There's a real chance that the meso-American corridor could be cut in half."

The fragmentation of the mangrove forests could also spell trouble for both the species and the people of Colón. After mangrove stands are cleared, the billions of liters of water that are usually entrapped by the thick network of mangrove roots flood the city regularly, especially during the rainy season, which displaces families and carries newly-exposed dirt, sewage, and toxins out to the corals in the near shore.

As with many fragmented tropical forests, as the population of mangroves near Colón become more patchy, so do their means of dispersal. Ivania Ceron, a graduate researcher from the University of Puerto Rico, just finished processing 1,000 samples of mangrove DNA that she collected from all across Panama -from Galeta, Bocas del Toro, the Pacific Gulf, and Darien National Park. Spending 10 days at each location, Ceron laboriously collected 250 samples per site. Red and black mangroves disperse aquatically by short-lived seeds; red mangroves can also reproduce by wind-carried pollen, black mangroves by bee-carried pollen. By examining chloroplasts, which are maternally inherited, and nuclear molecular markers, Ceron can see how the majority of the mangroves disperse as well as determine the contributions of seed and pollen. Preliminary analysis shows that seeds are overwhelmingly the favored mechanism.

Red mangrove (*Rhizophora mangle*) in bloom with seeds.

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Using a set of 11 genes, Ceron can trace, geographically, the spawn of one individual, in some cases as far away as 1,000 km. Ceron found a black mangrove in Bocas del Toro that was a direct relative of a black mangrove in Galeta, some 300 km away. However, the remarkable distance that the species can send their offspring is fragmented and interrupted by the unstoppable spread of

development. Over the next year, Ceron hopes to create a geographical family tree of the mangroves. "We have the genetic fingerprints for each individual," she says, navigating the boardwalk path through a forest of red and black mangroves, only steps from the ocean at Galeta point. "So we can compare them at all different scales. We can start here at Galeta and move out and out, examining this as a population, until we hit a genetic break [in the population]. This gives us a complete spatial genetic analysis."

Researchers in Colón must be quick in their work. "By the next time you come, this will all be gone," says Stanley Heckadon-Moreno, director of the Galeta marine lab, pointing from the passenger seat of the truck toward the mangroves just edging the Free Zone. Still, Heckadon-Moreno doesn't condemn the canal expansion project. The forests that line the canal (the former Canal Zone) are still intact only because they have been off-limits for so long to development or construction by Panamanians, he says. The expansion of the canal is necessary if Panama wants to continue to be vital to the world market, he adds.

Stanley Heckadon-Moreno is the director of the Galeta marine lab, which is on the border of a black and red mangrove forest outside Colón, Panama.

Still, the complete ecologic and economic effects that the expansion will have in Panama remain to be seen.

The Panamanian government put the decision to expand the canal to its people in a referendum that 80% of the voters approved in October 2006. Over the next seven years the Panama Canal Authority (ACP) plans to double the capacity of the canal to accommodate ships that can carry more than 12,000 containers. The expansion plan includes the construction of two additional sets of locks that will flank the already existing Gatun Locks (at the Atlantic head of the Gatun Lake) and the Miraflores Locks (at the Pacific end of the canal).

All told, the government estimates the project will cost $5.25 billion. According to the ACP's economic plan for the expansion project, the total proceeds from shipping transit tolls, after construction and maintenance costs, will be at least $1.72 billion each year the next 20 years.

In order to accommodate two lanes of ships, the depth, width, and volume of the channel and lakes must all be increased. In some places along the canal, such as the Culebra Cut, the ACP has been constantly widening since the canal first opened, but activities have ramped up since the expansion was approved (see sidebar "Expanding Evolutionary History"). Moreover, the canal is continuously dredged 24 hours a day to slow the buildup of sediment. Deepening the channel even further and dredging the Gatun Lake will provide more room for more water, in addition to raising the level of the lake by 45 cm. This increased water-storage capacity will be enough to operate the new locks, according to Daniel Muschett, manager of environmental management and monitoring at the ACP.

Some people question whether the Chagres watershed can supply the freshwater needed to operate the new locks and channels. Although Muschett says more than 60% of the water will be recycled in the locks, and the watershed has water enough to fill in new excavations, the water needed from the watershed after expansion will increase by 1.136 billion liters. Other environmental problems associated with the expansion "can be handled," says Jay Zieman, chair of the environmental science department at the University of Virginia. "Their biggest

problem will be where to find fresh water. They're going to have to pump other watersheds to get the water. And the beauty of the original canal is that there wasn't a pump in it."

According to Muschett, however, enough water flows from the Chagres to accommodate increased water needs in the canal. The watershed will likely be able to support the increased canal operations in most years, writes Steven Paton, director of the STRI office of bioinformatics, in an e-mail. STRI runs a hydrologic monitoring program of the canal watershed. However, he adds, years of extreme drought, as in 1998, may cause water shortages, and the whole system is a balance between increased traffic in the canal and human consumption, all subject to future increases and extreme weather conditions. "A change in just a few percent in any one of these can have huge implications for the canal's operation," says Paton.

"Thier biggest problem will be where to find fresh water. They're to have to pump other watersheds to get the water. And the beauty of the original canal is that there wasn't a pump in it."

-Jay Zieman

Muschett says that ACP has identified nine residences that are likely to be flooded during the three-month rainy season after the water level is raised. Other shorelines along the canal will likely recede further due to higher water levels and increased wave action.

Heckadon-Moreno says the STRI's primary concerns about the environmental impacts included salinization, water availability, and deforestation. Each lock uses 196 million liters of water each time a ship passes through: The water either floods the lock chamber to raise the ship or is drained to lower the ship closer to sea level. Muschett says any saltwater that is pulled into freshwater by the opening and closing of the 21-meter high lock gates is diluted by the freshwater coming from the watershed.

A nursery in Gamboa, Panama, grows more than 70 species of trees for Jefferson Hall's reforestation project. Often, nursery workers will travel into the local rainforests to collect seeds from native species.

Courtesy of Aaron O'Dea

Some STRI researchers have expressed concern that the environmental impact assessment (EIA) studies that the ACP conducted are, at the very least, not complete. In June, Laurence wrote in *New Scientist* that the government does not solicit rigorous EIAs and that the burden of proof of environmental impact rests on those who question the studies.[1] "Many EIAs are laughably superficial," writes Laurence. He cites a case involving a proposed apartment complex that would require clearing of forests. Surveyors hired by developers identified 12 bird species in the area, but when experienced bird-watchers conducted a two-hour census of the same area, they identified 121 bird species, many endangered or rare. The project was approved anyway.

STRI researchers are trying to come up with the best plan for replanting some already cleared areas edging the canal to compensate for the increased runoff and erosion caused by deforestation. The canal infrastructure itself is vulnerable

to heavy rainfall events. Jefferson Hall runs a replanting experiment on the hills bordering Soberania National Park, 15 miles northwest of Panama City. He is examining which species - both native and non-native - grow the fastest; the exotic teak is by far the best performing. However, all the planting lots are quickly overgrown by canal grass, an invasive species that chokes out the native species and encroaches on any open spots. By spearheading this project and another watershed-wide evaluation of water availability, Hall hopes to determine how to best manage water flow using plants and trees, especially during certain times of the year. "One ounce of dry-season water is worth its weight in gold for the operation of the Panama Canal," Hall says.

STRI's longest-lived research station at Barro Colorado Island in the middle of the canal has been purely devoted to science research since 1923. Docks and power generation buildings will have to be moved uphill from the water, says Oris Acevedo, the science coordinator there. A Panama native, Acevedo says she thinks some of the ecologic costs of the expansion project are well worth the financial and employment opportunities that the Panamanian government has said will accompany the project. "I think [the decision process] was very democratic," she says. "The government risked that we would say no." The increased canal income will provide vital services, including jobs and enhanced living conditions, she says. "If we don't do it, [another country] will."

It's late morning in Panama, and the steamy air coats everything and everyone with a slick residue. Dominique ("Dom") Roche, a graduate researcher at the STRI, drives a white Toyota pickup past the rigid security guards at the entrance to the Panama Canal Zone, on the west bank of the canal only a few kilometers from Panama City.

Down a bumpy dirt road, small coatis scatter at the sound of the truck, monkey-like tails bobbing after them. Roche slows suddenly, spotting the turn he's been looking for: a dirt path veering down the embankment to the left, almost completely overgrown by canal grass. The truck turns and descends slowly, as a still, green lake comes into view.

"We might see some crocs laying around down here," he says, sounding hopeful. Once at the shore of the 400-meter wide lake known as Miraflores Third Lock Lake, Carmen Schloeder and Yulang Kam hop out of the truck, pull on water shoes, and help Roche get a small motorboat off the truck's trailer and into the water. Kam's eyes scan the water intermittently for approaching crocodiles. The team piles into the boat and then speeds across the water.

Third Lock Lake is one of the abandoned excavation sites of the Panama Canal; dug out in the 1930s for a third set of locks but left uncompleted at the start of the Second World War. The water is brackish; freshwater and saltwater separate into distinct layers beneath the surface to create the perfect environment for *Rhithropanopeus harrisii*, the thumbnail-size Harris mud crab. An invasive species from the east coast of North America, *R. harrisii* is one of several exotic species that are under observation both in the canal and its extremities.

"In Panama, it's astonishing how little study there has been on the movement of organisms around the world as a result of the canal; 30 years with essentially no publication on the subject."
-Andrew Cohen

In the near corner of the lake Roche slows the motor and the team scours the surface for a red or white buoy indicating one of the traps they've set for the mud crab. "Did we put it more to the left, maybe?"

Schloeder offers. "I know we put one here in the corner," says Roche, but the buoy has sunk below the surface. "We'll have to bring back a long hook or something to fish it out next week."

14,000 ships travel the Panama Canal each year. Before the current expansion project, the Culebra Cut (right) was widened in 2001 by 222 meters in some places.

Roche, Schloeder, and Kam are researchers in Mark Torchin's lab at the Naos laboratories, STRI's molecular labs, on the Amador Causeway, which stretches onto a peninsula curving below the southern coast of Panama City. As the boat motors the length of the lake, the engine's hum reverberates off the black basaltic walls that were carved into during the original excavation. Eyes fixed on the water, they locate nearly every one of 25 traps (actually artificial habitats) they set in July to collect, count, and sex the crabs living in the lake. The *harrisii* species has been spotted all over the world, and five specimens were collected in the canal in 1969, but none since then. Indeed, Torchin's group placed a handful of traps in the canal itself, but to date they have yet to see a Harris crab there.

In Third Lock Lake, however, the species is abundant. In March, Torchin and Roche collected 88 specimens within one hour of inspecting the shoreline.[2] Among those collected, 16 were egg-carrying females, and eight were juveniles. The age distribution and abundance of the crabs suggested to Torchin that the lake is supporting a fully functional population of Harris crabs. But until Torchin completes more systematic surveys and expands his sampling distribution, it will be difficult to predict the effects that exotic species might have on the native ecosystem. His proposed project to monitor the crab and other invasive species in the canal area received funding in July.

"In Panama there is limited knowledge about [species] invasions," Torchin says, "and there hasn't been a standardized, quantitative survey of invasive species. People have done rapid surveys, but we're trying to set up a standard methodology and have it be quantitative."

Other invasive species that have been transported into the waters of the canal, thanks to the many ships on the waterway, include the Asian clam - which heavily populates the bottom of the canal's lakes and channels - and many fish species, including the peacock bass, Oscar fish, and tilapia. Other surveys have identified a dozen or so Atlantic marine species that live exclusively at the Pacific mouth of the canal, and vice versa.

Currently thriving in Third Lock Lake, the *Rithropanopeus harrisii* or Harris mud crab, is barely the size of a thumbnail.

Courtesy of Dominique Roche

A study published in 2002 showed that eight fish species had been established in the Chagres and Rio Grande rivers. The fish were introduced during the construction of the canal and established their populations by the 1930s.[3] The researchers also found that all native species populations (originally identified in

a 1910-1912 STRI census) remained intact. Nevertheless, "it's not reasonable to assume the impacts aren't there," says Andrew Cohen, director of the bioinvasions program at the San Francisco Estuary Institute.

Cohen adds that the canal expansion will directly impact the global scheme of shipping around the globe, with correlated shifts in the movements of organisms around the world as well. "In Panama, it's astonishing how little study there has been; 30 years with essentially no publication on the subject." With the expansion, "the whole intermeshed shipping network will shift, and no one has a handle on what that means when it comes to moving organisms around."

Torchin says that within the next year his group hopes to collaborate with molecular biologists to map the genetic origin of the mud crabs and possibly piece together how they came to be in Third Lock Lake.

A week after checking on the location of the traps, Roche and his assistants returned to Third Lock Lake to recover the habitats in their first of several collections over the next six months. Each trap is a square crate filled with seashells cinched into a mesh bag to capture any inhabitants. The specimens are taken to the labs at Naos to be counted and sexed. Just to the north of Third Lock Lake, the group collects specimens from another freshwater lake where they've also left traps. In the pacific entrance to the canal, they find that the tide has carried away some of the traps, which they replace and anchor with concrete blocks. The team also set up 20 traps in Miraflores Lake so it can begin monitoring crab populations there as well.

The researchers are in an unspoken race with the ACP, which plans to drain Third Lock Lake and begin construction of a third set of locks, beginning by the end of 2008. When the new set of locks is built, water will be redirected from the main channel of the canal to power them. The invasive crab population could be spread into the canal and adjoining waterways, become abundant, and clog drains and pipes. Or, the draining and construction in the lake could destroy the crab population. Either way, Torchin's team hopes to anticipate the outcome - if it can get enough done in time.

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Return to Top

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extremely high quality

by steven w vance

[Comment posted 2007-10-02 22:04:16]

This is my first exposure to The Scientist. It came about in a rather unexpected and casual way: I ride the train everyday to center City, Philadelphia to work in the investment planning field. I met Andrea on the R3 train, and we had quite a nice conversation about scientific writing. You see, I am an avid amateur scientist, with specialties in Catastrophic Geology, Paleontology, Natural Hazard evaluation and survival, and solid state (LED) lighting. Andrea encouraged me to subscribe, which I did. I must say that the quality of scientific writing and the presentation is AT LEAST the equal of National Geographic and Science, if not superior to them. Understandable yet sufficiently technical. Clear and thought-provoking. Cheers to Andrea for a job well done!!!