02

Dams and Disease

AN ECOLOGICAL SOLUTION
TO SCHISTOSOMIASIS IN SENEGAL

This anthology is a project of the Planetary Health Alliance (planetaryhealthalliance.org). The Planetary Health Alliance is a consortium of over 200 partners from around the world committed to understanding and addressing the human health impacts of global environmental change.

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Please cite this case study as “Duff H., Faerron Guzmán, C., Almada, A., Golden, C., and Myers, S. "Dams and Disease: An Ecological Solution to Schistosomiasis in Senegal." Planetary Health Case Studies: An Anthology of Solutions. 2020; https://doi.org/10.5822/phanth9678_2

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Executive Summary

Many of the ideas and themes in this case study are explored in depth in chapter 6 on infectious disease in ↘ Planetary Health: Protecting Nature to Protect Ourselves.

Learning Objectives

After the case discussion, in relation to the Senegal River Basin and the construction of the Diama Dam, students should be able to:

① Understand the short- and long-term positive and negative outcomes of large dams.

② Appraise the unintended health consequences of large dams, particularly in relation to schistosomiasis.

③ Analyze social and environmental factors that influence schistosomiasis transmission.

④ Assess the challenges associated with scaling and sustaining solutions to planetary health challenges, especially in relation to schistosomiasis.

⑤ Apply systems thinking principles to the analysis and solution-seeking process of planetary health challenges.

This case study is about the effects dam building and land use change have had on schistosomiasis, a parasitic disease, in the Senegal River Basin in West Africa. Construction of the Diama Dam at the mouth of the Senegal River was intended to bring various human health and economic benefits. While there were some positive impacts, the dam also had unintended consequences. For one, it affected the life cycle of a native river prawn, hindering its essential migration to the mixed fresh and saltwater estuary near the Atlantic Ocean. An important predator in the river ecosystem, the local extinction of prawns led to an upstream explosion in the snail species that serve as a reservoir for schistosomiasis. Disease rates spiked and schistosomiasis has been endemic in Senegal since the dam was completed in 1986. As similar human infrastructure projects are proposed worldwide, it is key to understand the effect these developments could have not only on the environment but also on human health.

Past interventions addressing schistosomiasis have focused on the distribution of therapeutic drugs. These campaigns have been unsuccessful in countries like Senegal. One reason is because they fail to consider how social, ecological, economic, cultural, and health access factors affect the transmission of disease. A team of researchers and civilians called The Upstream Alliance are mindful of these complexities and the original ecosystem balance that kept snail populations in check. The group proposes re-introducing the native prawn species as an ecological intervention to complement drug therapy. This intervention has been found to reduce schistosomiasis rates and, if successful and sustainable, could provide food and livelihood security for people living in the Senegal River Basin.

This case study is based on interviews conducted in the Senegal River Basin and Dakar, Senegal in April 2019.

Introduction

"Look how beautiful they are, I love them!" Dr. Susanne Sokolow is gushing as she peers into a large basin, roughly the size of a backyard swimming pool. She's referring to the 300-some prawns skittering around the base of the tank. Sokolow's enthusiasm for these crustaceans, and the prawn hatchery that houses them, is understandable. These prawns are in many ways the culmination of the decade-long efforts of Sokolow and others in the West African country of Senegal. Sokolow is a disease ecologist and veterinarian at Stanford University, and a co-founder of The Upstream Alliance, a partnership of scientists and citizens from four continents, all equally dedicated to the promise of these particular prawns.

Not far from this prawn hatchery lies the Senegal River, the 1,800-kilometer-long band of water that traces the border between the countries of Senegal and Mauritania. The Senegal River Basin's landscape is arid desert that extends from the Sahara and stretches across much of the region. The river and its tributaries are the water source for the 3.5 million people in four countries who live, farm, and fish within the basin.[1]

The prawns in this hatchery are being raised to support the health of nearby villagers in surprising ways. The crustaceans could reduce rates of schistosomiasis, a parasitic disease that infects an estimated 240 million people worldwide and puts more than 700 million at risk.[2] The World Health Organization estimates 200,000 people die from schistosomiasis each year.[3] Over 90% of the people infected live in sub-Saharan Africa, and schistosomiasis is second only to malaria as the most burdensome parasitic disease globally.[4][i]

Senegal is one of 52 countries where the disease is endemic[5], meaning levels of infection are consistently maintained. This is especially true in the Senegal River Basin, where there has been a high and continued incidence of schistosomiasis since the late 1980s.[6][ii]

Regional inequity is to blame. Schistosomiasis is a disease of poverty, disproportionately affecting people who live in low-income settings without access to safe drinking water and sanitation. It has been deemed a neglected tropical disease[iii] as a result of the people it affects and the comparative lack of attention it receives from funders*, governments, media, and researchers alike. Worldwide, less than half of people infected receive drug treatment.

[i] Which countries are affected the most by schistosomiasis? ↘ Learn more here

[ii] Other than the new number of cases (i.e., incidence), how else would you measure the burden of this disease?

[iii] What other diseases fall under this category of neglected tropical diseases? ↘ Learn about NTDs here

*For context, the World Health Organization estimates there were 228 million malaria cases worldwide in 2018, and 405,000 deaths. It reports that US $2.7 billion was available for global malaria control and elimination programming that year. Meanwhile, the WHO says the total amount spent on all 18 Neglected Tropical Diseases (including schistosomiasis) amounted to between $200 million and $300 million a year between 2012 and 2014.

When interventions do occur, mass drug administration campaigns have been the public health community's control method of choice. The Upstream Alliance's complementary contribution is prawns, a predator of the snails that serve as the reservoir host for the parasite that causes schistosomiasis. Research has shown that restoration of native river prawns can reduce the number of snails—and as a result, the prevalence of disease—in the Senegal River Basin.[7] It's one part of an ecological solution that, if scalable in the way The Upstream Alliance envisions, could be a triple-win for human health, restoring the ecosystem, and alleviating poverty.

Aquaculture engineer Papa Demba Ndao gestures at the prawns at the hatchery outside of Saint-Louis.

Senegal: The Gateway to West Africa

Located at the westernmost point of the African continent, Senegal is known as the "Gateway to Africa." The country's economy is one of the strongest in sub-Saharan Africa, with economic growth exceeding 6% every year since 2015.[8] Macky Sall was re-elected as President in February 2019, and is implementing the second phase of "Emerging Senegal," his economic and social development plan that started in 2014. That plan includes a focus on agriculture and aquaculture, the practice of farming fish, prawns, and other aquatic species.

Agriculture is Senegal's most important industry. Farming, fishing, livestock rearing, and other livelihoods employ an estimated 60% of the labor force.[9] The fishing industry is evident from the large wooden boats that line the oceanside of coastal cities like Saint-Louis—what's less outwardly visible is the farmland. Main highways in the north of the country cut through sandy desert landscapes, clustering most agricultural land around the Senegal River Basin, its tributaries, and the large Lac de Guiers. With a growing population[iv] and changing climatic patterns, development projects such as dams and irrigation schemes have been expanding to support farming and livestock husbandry by providing year-round access to freshwater. While these developments were designed to increase available land for agriculture and the generation of clean energy, they can also alter ecosystems and cause unintended human health consequences.

[iv] How does population growth in Senegal compare to that of your country of origin?

Those negative health effects disproportionately affect people living in rural regions where healthcare access can be limited. Over half of Senegal's population of 15.4 million people live in urban centers, including the capital city of Dakar.[10] While wealthier Dakar residents have geographic and economic access to medical care, there are significant inconsistencies in accessing health services in peri-urban and rural areas, including the Senegal River Basin. This is partly due to decentralization of health services, and the fact that each of the country's 14 regions independently decide how to spend their healthcare budget. However, it has been reported that local governments contribute less towards local healthcare services than they're legislated to do.[11][v]

[v] Do you know how your health care is funded?

This gap in funding means people often need to pay for health costs out of pocket, including medication to treat diseases like schistosomiasis. It's estimated that more than a third of national health spending comes from the wallets of everyday Senegalese rather than through insurance, with individual patients paying for care and medication at healthcare facilities[12], similar to other parts of the world without universal healthcare. This figure is high in a country where, on last measure in 2011, 46.7% of the population lived below the national poverty line.[13] The Senegalese government has made strides in improving healthcare access for some demographics and diseases. For example, free healthcare is provided to newborns under the age of one and people over 60, and the country has a comprehensive tuberculosis treatment program.

Small health posts overseen by a nurse or midwife are the first point of care for most Senegalese, and represent 90% of the country's public healthcare facilities.[14] There are also 14 regional hospitals across Senegal, though these are found in the regional capital cities which are still commonly inaccessible due to cost or travel time. More serious health cases are referred to one of the national hospitals in Dakar.

These barriers in reaching and affording healthcare treatment have become more urgent in the last 30 years as new infrastructure projects have increased the prevalence of schistosomiasis in the Senegal River Basin.

A Senegal River Basin village seen in proximity to the river—and the desert landscape. (photo courtesy of Andy Chamberlin, The Upstream Alliance)

The Diama Dam and the Dynamics of Land Use Change

A herd of cows strolls lazily alongside the irrigation canal that connects the Senegal River with Maguette Diop's family land. With the dust and dry of the surrounding environment, arable farmland is an unexpected sight. Diop lives in Maka Diama, a village about seven kilometers from this property. His daily commute is via the horse-drawn cart that sits at the edge of the field. He and his family alternate what they grow on this land—half of the time it's flooded as a rice paddy field and the other half, like now, it's filled with small green onion sprouts. Both are essential sources of food and revenue for the family.

Maguette Diop in his family field.

Year-round agriculture hasn't always been possible in the Senegal River Basin. The region faced two pressing challenges by the turn of the 1970s: persisting drought and a growing population. Located in the Sahel region where the Sahara Desert transitions into the tropical ecosystems of sub-Saharan Africa, climatic variability is dramatic and precipitation scarce. This was especially true during the 1970s and 1980s—average rainfall in the Sahel had decreased by more than 30% when compared to 1950 levels.[15] This put the predominantly agricultural region in a precarious state.

Drought resistant crops such as sorghum and millet were not new, and their production was increasing at a rate of 1% a year. However, this agricultural yield was outpaced by a 2.5% annual population growth.[16] Further, governments in the region prioritized the cultivation of cash crops such as cotton and peanuts for export, neglecting the food needs of the growing population. It was the making of a food crisis, and national governments feared the political and social instability that could come if prices were raised and basic food needs unmet.

All the while, low precipitation levels meant a drop in groundwater supply. This allowed saltwater from the Atlantic Ocean to seep into freshwater aquifers and flow up the Senegal River, reaching 250 kilometers inland. Salinity in groundwater stores increased and further limited the land suitable for agriculture and the water available for household use.[vi] This shortage of arable land led to actions that stressed the environment but were necessary to meet food production demands. This included the cutting of trees to create more inland farming areas and planting farm plots year after year, preventing nutrients from being restored.[17]

[vi] How does this process of salinization happen? How will increasing temperatures affect this process? Who is most at risk?

In response to these freshwater access challenges, the West African countries of Senegal, Mauritania, and Mali came together in 1972 to form the Organisation pour la mise en valeur du fleuve Sénégal (Organization for the Development of the Senegal River, OMVS).[vii] OMVS's first act was to propose a technological solution: two dams to be installed in the river basin.

[vii] The West African country of Guinea joined the alliance in 2006.

Expectations for the dams were high. Objectives included ending the basin's food shortage crisis by expanding the area for irrigated farmland, producing hydroelectric power, and maintaining river water levels to allow for navigation and use by irrigation canals.[18] The primary purpose of the Diama Dam was to block saltwater from further intruding into upstream groundwater supplies and soil. Saltwater intrusion is expected to become a greater problem worldwide as sea levels rise, precipitation patterns shift, and a greater demand for freshwater stresses groundwater supplies to the point where seawater begins to seep into the source.[19]

Envisioned as a fix-all solution for the region's challenges, construction of the Manantali and Diama Dams were enough to temporarily band the member states together towards a shared purpose. Senegal, Mauritania, and Mali handed control of their land and river works over to OMVS in order for the pair of dams to be constructed.[20] The Diama Dam opened in 1986, approximately 30 kilometers inland from the coastal city of Saint-Louis, Senegal. The Manantali dam opened two years later, a further 1,150 kilometers upstream along the Bafing River in Mali.

Amadou Mbodji waters his green onions in the arid landscape of northern Senegal. The water used on his farm and others would not have been available without the construction of the Diama Dam.

The project received ample criticism. "The worst possible solution," said one critic.[21] There were concerns that OMVS's intentions might be misleading. "Once more, peasant farmers are being used as an alibi. In theory, all this is being done for their benefit," proclaimed a French agronomist in a 1982 publication.[22] He continued: "if one looks more closely, one notes that the dams have already benefited: the consultancy firms that have already earned several thousand million francs in fees, and hope to earn much more; [and] the bureaucracy of OMVS and its counterparts in each of the three member States."

Criticism wasn't unfounded. A British consulting firm hired to do a pre-construction evaluation of the project deemed the need for two dams unnecessary, stating that one would have likely been fine without the other.[23] OMVS ignored these recommendations, constructing the two dams as planned.

The Diama Dam achieved its mission in some ways. Protection against saltwater intrusion and a new series of irrigation canals led to a higher availability of freshwater. Land with access to irrigated agriculture grew over 24-fold.[24] That benefited farmers like Maguette Diop, whose original family land in Maka Diama was flooded and covered with aquatic vegetation following the construction of the dam. Like many other farming families, Diop had to shift where his land was located and adopt new methods of agriculture. The initial impact of this was challenging: not only is tending an irrigated field different than relying on annual patterns of flooding and precipitation, but the displacement and reassignment of new farmland led to land tenure conflicts across the basin.[25]

Still, Diop admits the Diama Dam brought his family more benefits than setbacks. "Before the dam was constructed we couldn't do farming activities during the dry season but now farming is possible through the whole year," he says, gesturing to the nearby irrigation canal.[viii] "If we weren't able to water our fields it might get complicated for us because farming is the main activity in this region." While the construction of the dam allowed for year-round freshwater access from irrigation canals, it also contributed to a 50% decline in the Senegal River Basin's fishery.[26] Certain species in the river fishery required a mix of salt and freshwater to complete their life cycles, conditions that were not possible after the construction of the Diama Dam.[27]

[viii] The distribution of irrigation water in Senegal is overseen by a number of groups, including organizations operating at arms-length from the government and NGOs.

More detailed cost benefit analyses have revealed the true value of the dam infrastructure 30 years after construction. Despite the initial financial revenue that came from increased agricultural activity, it's calculated that the dams cost the region approximately US $572.1 million over 20 years due to lost productivity, environmental degradation, costs to human health, and other social impacts.[28] [ix]

[ix] How do you think this is estimated?

Disrupting the Predator-Prey Relationship

The Diama Dam altered the upstream ecology of the Senegal River. Just as the dam blocked saltwater from reaching upstream, it also prevented the flow of aquatic species in the opposite direction from river to sea. That had devastating effects on the river's population of *Macrobrachium vollenhoveni*, a native species of giant river prawn that needed to travel up and downstream to complete its lifecycle. Survival of the species requires that female prawns migrate to the brackish water of the estuary in order to lay their eggs and raise larvae. Once the larvae reach adulthood, prawns would normally migrate back upstream to the freshwater environment. The dam trapped them on one side of an impassable concrete structure.[x]

[x] This has been described in other parts of the world, but with other species. Has it happened in your country or region? Why or why not?

Trophic Cascades

Trophic cascades involve the addition or removal of an ecosystem's top carnivorous predator. Present worldwide, trophic cascades send complex ripples through food webs.

One of the most well-known trophic cascades was the local extinction of wolves from Yellowstone National Park. Killed off in the early 20th century as part of predator control programs meant to protect domestic livestock[29], the absence of wolves saw an increase in deer in the park. The deer population had previously been kept in check because of predation from wolves. Liberated from predatory pressure, the deer grazed leisurely through the park's flora, decimating plant species to the detriment of other species in the park. Since the reintroduction of wolves to Yellowstone in 1995, the deer population has been re-regulated, erosion decreased, and species of all kinds, from beavers to songbirds to fish, have benefited from the natural restoration of order in the ecosystem.[30]

Trophic cascades don't always have positive endings. Another case study in this anthology details the trophic cascade triggered when the non-native Nile perch was introduced to Lake Victoria for sport fishing purposes. That introduction had devastating implications on the ecology of Africa's largest lake and continues to affect people living on its shores today—including possibly increasing the risk of schistosomiasis as the non-native perch out-compete native cichlid species that kept snail populations in check.

One of the water access points where Senegal River Basin village residents get much of their water for drinking, cooking, and other daily activities. (photo courtesy of Andy Chamberlin, The Upstream Alliance)

Not only an important food source for Senegal River villages, the prawns played a key role in the ecosystem's food web.[xi] They served as a natural predator for the many small snail species that existed within the river. With no predator and blooms of aquatic vegetation caused by newly stagnant water, the snail population thrived. That wasn't good news for human health: the more snails, the more parasitic reservoirs. Two years later, people living upstream from the dam started urinating blood[xii] and displaying other symptoms of schistosomiasis. It was a turning point for the health of people living in the Senegal River Basin.

[xi] Before moving forward, can you find out what the food web in Senegal might have looked like before the dams were built?

[xii] This is known as hematuria.

Recognizing the surprising consequences of dams on disease is an urgent problem worldwide. Only one-third of the world's long rivers remain free of man-made dams and other infrastructure.[31] The number of similar infrastructure projects is expected to continue to grow as countries transition from fossil fuel derived energy to cleaner sources, and as freshwater supply decreases with climatic variability.

Worldwide, nearly 400 million people are at a higher risk of contracting schistosomiasis, partly because dams have blocked the migration of snail-eating river prawns.[32] Though prawns are not the only predator for snails, they are a significant regulating force. Additionally, dams bring increased human migration due to the agricultural or industrial development they support — a social driver that can increase risk of schistosomiasis.[xiii]

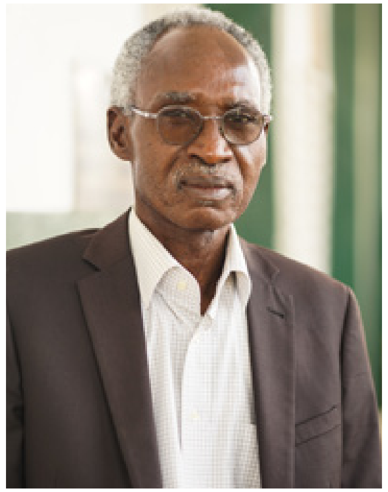
[xiii] Start thinking of all the determinants of health that are at play in the context of schistosomiasis.

Take, for example, northern Egypt, where schistosomiasis prevalence[xiv] increased from less than 20% to 75% in some areas after a new dam was constructed in the 1930s.[33] This was attributed to an increase in the snails that serve as a host for the disease. Today, people in sub-Saharan Africa living within five kilometers of dam reservoirs are at increased schistosomiasis risk, as are people living closer to dam-supported irrigation systems.[34] New dams are still being constructed worldwide without the necessary consideration of not only their environmental effects but also their public health implications.

[xiv] It is unspecified whether this was an increase in intestinal or urinary schistosomiasis.

Origins of an Outbreak

[xv] Sugarcane in Senegal is produced by the Compagnie Sucrière Sénégalaise (CSS), which basically acts like a state-owned monopoly for sugar production.



Dr. Idrissa Talla outside of his office in Dakar, Senegal's capital city.

January 13, 1988. Dr. Idrissa Talla recalls the date without a moment's hesitation. He's sitting in his office at the Universite Amadou Hampathe Ba in Dakar, where he serves as head of the Community Health Programme in the public health department. In 1988 Talla was in a very different position, geographically and seniority-wise.

Four years into his career, Talla was appointed as the medical doctor in charge of the health district of Richard Toll, a rapidly-growing town in the Senegal River Basin known for its sugarcane production.[xv] The factory was big business, and people were flocking from across the country and West Africa to seek employment. The population boom soon put a strain on freshwater resources, and the town's small reservoir was insufficient for the expanding community. The dam had provided increased freshwater for agriculture, but not for the growing population. People spent their days centered around the network of irrigation canals that channeled water from the river into the sugarcane fields. They'd work in them during the day and, as a result of the limited reservoir, use the same water for domestic purposes like cleaning, bathing, and drinking. "People were very closely in touch with the water," Talla describes.

That intimate relationship between people and their limited water resources had human health consequences. "A colleague, the only microscopist at the district laboratory, knocked on my door and said 'Dr. Talla, I saw something very bizarre and I don't know what it is,'" recalls Talla of the January day in 1988. Initially brushing off the concerns, his colleague persisted. Eventually, Talla and two other doctors went to the laboratory. Looking in the microscope, they were perplexed by what they thought they saw: the eggs of *Schistosoma mansoni*, the parasite that causes intestinal schistosomiasis.

Talla and his team requested another stool sample from the patient. And then another. "We put the slides under the microscope and it became more and more clear—this thing is schisto." Talla quickly ordered a meeting with the nurses and midwives, demanding stool samples be collected from all patients. "We were surprised. Almost every single person was infected," Talla says.

The outbreak happened virtually overnight. *Schistosoma haematobium*, which causes urinary schistosomiasis, had first been described in the Senegal River Basin in 1908, and by the 1960s the disease was found across the country.[35] Cases of intestinal schistosomiasis, however, were rare in the region. In 1988, only 1.9% of stool samples collected from Richard Toll residents tested positive for intestinal schistosomiasis. By the end of 1989, 71.5% of stool samples showed evidence of these parasitic eggs.[36]

Acute symptoms of intestinal or urinary schistosomiasis can include fever, chills, cough, and muscle aches. Chronic schistosomiasis can cause abdominal pain, an increased risk of liver fibrosis and bladder cancer, and bloody diarrhea (for intestinal schistosomiasis) and painful urination and blood in the urine (for urinary schistosomiasis). According to the Centers for Disease Control and Prevention, repeated infection in children can lead to anemia, malnutrition, and learning difficulties, as cognitive growth is affected by parasitic eggs reaching the brain.[37]

Talla and his team were shocked by the discovery of intestinal schistosomiasis. The environmental impact assessment performed before the dam's construction had suggested there would be an increase in urinary schistosomiasis, but said intestinal schistosomiasis wouldn't be possible because of the environmental conditions.

Contrary to all that was suggested, the Richard Toll health center had an outbreak on its hands. Talla published the findings in an international journal without seeking permission from the national Ministry of Health, fearing they'd try to downplay the findings. The study attributed the outbreak to two factors: construction of the Diama Dam which introduced environmental alterations and the demographic shifts that came as people migrated to Richard Toll from countries where intestinal schistosomiasis was persistent.[38]

The paper was widely read, and an international contingent of schistosomiasis scientists soon converged on Richard Toll. "I was very tiny at the time, just around 30-years-old. I think they wondered 'who is this small bush doctor talking about schistosomiasis?'" Talla laughs. He took them to the irrigation canals to see the snails. "We took them from the water, went to the lab, and heated them with a lamp. When we exposed them to the heat the cercariae[xvi] came out. Everybody looked at that incredulously and said 'ah, now we are convinced!'"

[xvi] Cercariae are the larval stage of the parasite.

The cercariae that Talla and the team of scientists saw under the microscope are central to understanding the life cycle of the parasite and the transmission from snail to human. As for the place of transmission itself—you just need to find the water.

A disease with an environmental reservoir

There are two very different types of activity happening along the shores of Mbarigo village. The village of 600 sits on a tributary of the Senegal River. This shallow watering hole is one of three points where residents have direct access to fresh water.

The water is a cloudy mix of sediment and soap. It surrounds a group of young girls doing their afternoon chores, including 16-year-old Nafissatou Diagne. Knee-deep in the water, Nafissatou is scrubbing her family's colorful woven mat. She stops occasionally to adjust her pink skirt, gingerly lifting the bottom seam from the water's surface.

On either side of Nafissatou, Dr. Susanne Sokolow and Souleyman are wearing a slightly different uniform. Donning the high waterproof boots often worn when fishing, their movements are surprisingly agile as they scoop vegetation from the river bottom. Mossy vegetation undulates gently around their legs.

Raising her scoop from the water, Sokolow picks through the knotted vegetation searching for snails. "The *bulinus* snails are super attracted to this plant, probably because of all its surface area. They get to eat all the algae on here," she says. She extends a gloved hand to reveal the miniscule snails she's extracted from the vegetation.

Schistosomiasis is a vector-borne parasitic disease. It relies on an environmental reservoir, meaning its transmission cycle includes a significant component in the environment outside a human host. This is the case for many of the world's most prevalent diseases: malaria, typhoid fever, and zoonotic diseases such as Ebola and Nipah virus, just to name a few. In the case of schistosomiasis, the environmental component is the time the parasite spends in snails, as well as in the water in search of a human host. "Because the pathogen of these diseases stays in the environment for a considerable amount of time, there is the obvious opportunity for a wide range of environmental drivers to affect their survival," says Dr. Giulio De Leo, a Stanford University biologist and Science

A young girl in Mbarigo village washes her family's lunch dishes. This is just one of the many activities that happen at these water access points. These water outlets are as much a community gathering spot as they are a bathtub, kitchen sink, and toilet for local villages.

Director of The Upstream Alliance. Environmental changes like warming, deforestation, or introduction of new species can increase or decrease the persistence of parasites in the environment. That includes boosting the population of river snails by installing a dam at one end of an ecosystem.[xvii]

[xvii] Do you know of other examples where something similar has happened?

Typha Taking Over

Prawns and snails were two species impacted by construction of the Diama Dam. Another ecological effect of the dam was an increased abundance of *typha*[xviii], an invasive wetland reed that thrives along the riverbanks of freshwater ecosystems.

In no place is this altered river ecology more apparent than at the Diama Dam itself. Standing along the land barrier that separates the dam and the Mauritania side of the Senegal River, one can easily see the difference between the natural and altered ecology.

On one side, the bank of the river is still visible and bare of vegetation; on the other, a dense mat of healthy *typha* fringes the river's edge. Its increased abundance is both a nuisance and a public health risk. For one, its overgrowth restricts the ability of villagers to reach their water access points.[39] *Typha* can also clog pumping stations used to supply water to irrigated agriculture.

Typha has also been connected with the presence of schistosomiasis. In Zimbabwe, an increased number of snails has been found to correlate with the presence of *typha* reeds,[40] and the same is suspected in the Senegal River Basin. *Typha* is common in each of the water access points studied by The Upstream Alliance in the Senegal River Basin.[41]

[xviii] Pronounced TEA-fuh. Goes by the common name cattail.

Raphael Ndione from the Senegalese biomedical research centre Espoir pour la Santé (EPLS) works with Andy Chamberlin and Dr. Susanne Sokolow from Stanford University to collect snails from the shore of the Senegal River. These snails will later be dissected and examined for the microscopic parasite that causes schistosomiasis.

Schistosomiasis is caused by a parasitic organism that lives either on or in a reservoir host. In Senegal, there are three common species (and a few other less common species[42]) of snails that serve as the intermediate reservoir host for the schistosomes that infect humans[43], though other mammals like livestock can also be hosts. Infection happens when people come in contact with parasite infested waters.

Driven by warm temperatures to leave the snail's shell, the parasite propels itself through the water in search of a human or mammalian host. This is why, at the water access point in Mbarigo village, Sokolow and Souleyman are wearing wader boots. It's also why the group of girls, including Nafissatou, are at risk of contracting schistosomiasis.

Once the parasites have found a human host, they burrow through the skin and live as adult worms in the veins surrounding the bladder (for urinary schistosomiasis)[xix] or intestines (for intestinal schistosomiasis). Female worms can lay as many as 300 eggs per day.[44] Bearing a sharp barb on their side, eggs become lodged in human tissue. This deposition of eggs and their exit from the body can cause severe tissue damage and is the cause of blood in a person's urine or stool. ↘ *Appendix 1: CDC schistosomiasis diagram*

A person infected with schistosomiasis is immediately at risk of spreading the disease to others by urinating or defecating the eggs into or nearby a water source. The eggs hatch into larvae which find a new snail host, completing the life cycle. More snails, more schistosomes, and an increased likelihood of people coming into contact with the disease.[xx]

[xix] Schistosomiasis has a specific tissue tropism to these organs. What other parasites have a particular affinity for certain organs? Why do you think this happens?
↘ Learn more here

[xx] How many people in your country do not have access to improved sanitation facilities? How about in Senegal? And in the world?
↘ Learn more here

The health and environmental consequences weren't of particular surprise to OMVS, the group behind the Senegal River dams. "We knew that we were going to face many problems after the construction of the [Diama] dam, but when we compared the drawbacks and the advantages we realized there were more advantages," says Adama Cheibany, technical manager of the Diama Dam. He again references the increase in irrigated agricultural land, the availability of freshwater, and the generation of clean energy provided by the Diama Dam's sister project, the Manantali dam. "Now we are trying to minimize the negative impacts," Cheibany says.[xxi]

[xxi] If you were to weigh the pros and the cons of the large infrastructure project, what things would be most important to you when making a final decision on whether to build it or not?

Tapped water is available in some Senegal River Basin villages, but it costs money to access. Despite understanding the connection between the water and schistosomiasis, poverty means that many people have no choice but to continue using the river.

Past Interventions: Mass Drug Administration and Sanitation

[xxi] These approaches are known as reductionist approaches. Do you know what the opposite approach is called?

[xxii] Have you ever been exposed to an MDA campaign?

There have been several unsuccessful attempts to reduce or eliminate schistosomiasis rates in the Senegal River Basin. A reason for that failure is that interventions typically target only one arm of transmission, focusing on the reduction of disease in humans while ignoring that the problem is also mitigated by environmental conditions.[xxi]

A decade before the first cases of intestinal schistosomiasis were discovered in Richard Toll, another medical discovery was made. The innovation was praziquantel, a new therapeutic drug to treat parasitic worm diseases, including intestinal and urinary schistosomiasis. By the mid-1980s an estimated one million patients had been treated safely and successfully on three continents[45] and the global health community was optimistic that praziquantel could be a means to treat schistosomiasis.

By 2001, the distribution of praziquantel through mass drug administration (MDA) campaigns had become the key control strategy for schistosomiasis worldwide. MDA is the treatment of targeted populations without individual diagnoses.[xxii] In the case of schistosomiasis in Senegal, the campaigns targeted school-age children between the ages of 5 and 14-years-old. This demographic has the highest risk of schistosomiasis infection and faces the longest-term health implications due to their young age.

Praziquantel is highly effective under certain circumstances. A trial from the 1990s found that two treatments of 40 mg/kg given 40 days apart "cured" three out of four individuals—meaning they had "worm burdens below the detection level."[46] Double doses of praziquantel given in this schedule also reduced the intensity of schistosomiasis by 88%, which is to say individuals had a lower burden of worms in their system.

However, most Senegal River Basin residents are not able to get two doses of praziquantel treatment. This is usually because of the cost of the medication and an inability to reach a health post to purchase the drug. Since 2009, annual large-scale MDA campaigns have aimed to address schistosomiasis in Senegal. During those campaigns, doses of praziquantel are distributed to school-age children and at-risk adults. Funding for Senegal's National Control Program currently depends on the World Bank.

High costs and an inability to distribute praziquantel more frequently are two of the challenges and limitations to MDA campaigns, says Dr. Gilles Riveau, CEO of the Biomedical Research Center Espoir Pour La Santé (BRC EPLS), a Senegalese institution based in Saint-Louis. BRC EPLS has been addressing schistosomiasis and other parasitic diseases in the Senegal River Basin since 1991, and the institution's research helped influence the methodology of the country's MDA campaigns. "You have to find a way to use [praziquantel] that meets the economic and access issues in a country," Riveau says. 'How can you reach the people with the products? What methods will you use? Who will give the drugs? You develop an incredibly long list of questions and you have to find the way to be the most efficient."

Schistosomiasis Vaccine: A Work in Progress

Researchers around the world, including in Senegal, have spent the past several decades working towards a schistosomiasis vaccine. It was under the pretense of developing a vaccine that Biomedical Research Center Espoir Pour La Santé (BRC EPLS), a Senegalese research hub and NGO was founded in 1995 by Dr Gilles Riveau. BRC EPLS is The Upstream Alliance's scientific and community partner in Senegal.

Bilhvax (Sh28GST), a vaccine for urinary schistosomiasis, showed promise when trialed on non-human primates and cattle. However, human clinical trials have yet to show efficacy.[47] The most recent phase III of clinical trials involved 250 school-aged children in the Senegal River Basin. The vaccine was administered alongside praziquantel to see if together they could delay reinfection of the disease. Follow-up assessments over the course of three years found there was no significant difference between the half of children who had gotten the Bilhvax vaccination versus those who were injected with a placebo.

Another vaccine currently in clinical trials is the Brazilian-developed SM14/GLA-SE. The next trial phase will involve 95 school children living in areas of the Senegal River Basin. BRC EPLS is overseeing this trial and supervised the one performed for Bilhvax. While vaccine development and testing is underway, BRC EPLS relies on other interventions to lessen the burden of disease in the basin. That includes working with The Upstream Alliance on the prawn project, and also supporting government MDA campaigns for praziquantel.

"We wanted a tool to fight the pressure of the disease, and praziquantel leaves people in relatively good shape even if they will be reinfected one day after," says Gilles Riveau, Executive Director of BRC EPLS. "It wasn't logical for us to think we could only focus on the vaccine if you remember that we are at the service of the population. In the short term we have to use praziquantel and in the far future we have to work on a vaccine."

Like the prawn intervention, there is the possibility that a successful vaccine be incorporated into control programs for schistosomiasis alongside existing interventions like praziquantel rather than being seen as a standalone "silver bullet" solution.

Dr. Idrissa Talla later became head of the National Control Program of Schistosomiasis. He agrees that the logistics of praziquantel distribution were the greatest obstacle. “The medicine was there, people were trained, and the populations were aware of the necessity of the medication. But you still had logistics. The government needed to give us cars, but we had to ask for money outside of the country instead. That was a weakness, and I think that it hasn’t much changed,” he says.

MDA campaigns have another catch: even if there was a way to regularly treat those at risk of contracting schistosomiasis, it still wouldn’t be enough. The drug kills only the adult worms in humans, and doesn’t address the environmental reservoir—the snails. That means a child treated as part of an MDA program can go back into the water an hour later and not only get new worms, but release eggs into the water if they urinate or defecate nearby. The cycle continues.

From Corsica, With Love

Schistosomiasis has recently made the news in unexpected places. A popular tourist destination in the middle of the Mediterranean Sea, the French island of Corsica experienced an outbreak of over 120 cases of urinary schistosomiasis in the summer of 2013. Tourists and locals, some of whom had never left Europe, were exhibiting symptoms of schistosomiasis after swimming in the island’s Cavu River.

Interestingly, the cases in Corsica were caused by a hybrid of two schistosome parasites. Just as travel contributes to the spread of parasites worldwide, studies suggested the schistosome culprits in this outbreak could have been introduced by a person who was either infected in or visiting from Senegal.[48]

Ultimately, it’s not enough for an infected individual to urinate or defecate near a water source—there also needs to be the correct species of snail to serve as a reservoir for the disease. While the implications of precipitation, climate, and land use change on snail populations and schistosomiasis prevalence are still being determined, initial research suggests snail survival rate is affected by temperature.[49] Further data show that deforestation in some areas can favor transmission of schistosomiasis and other vector-borne diseases by allowing more sunlight and warmth to reach water bodies. Overall, changes to the Earth’s natural systems could eventually lead to high rates of schistosomiasis in some areas and a reduced risk in others.

According to Dr. Giulio De Leo, it’s important to remember that there will be people who win and lose with these environmental changes. “An increase in temperature might actually remove a disease in places that become unsuitable for the parasite to complete its life cycle because it’s too hot,” he says. “Given the level of climate change expected and the extent of land use change through agriculture and urbanization, we know we are going to be dealing with these new challenges in the future to come.”

“The pills work great, it’s just that in a zone of transmission that’s as high as this, kids end up being almost on a treadmill where they’re treated and they get re-infected at such a rate that it negates the treatment,” explains Dr. Susanne Sokolow. “If it were a low risk area where you wouldn’t acquire new worms so rapidly after going back in the water, then you could march towards elimination through drugs alone.” Today, prevalence rates of urinary and intestinal schistosomiasis among children in the Senegal River Basin are estimated at between 90 and 100%.[50]

The Socioeconomics of Disease Transmission

Schistosomiasis transmission is also exacerbated by social and economic factors, variables that can’t be addressed by drugs. Transmission of disease requires exposure to infected water, and the water access points of villages and murky rice paddy fields provide an ideal environment. In theory, improved sanitation and drinking water infrastructure could reduce the risk of transmission, but that hypothesis is imperfect in real-world application.

A 2004 study investigated the hygiene practices of children and mothers with infants in Northern Senegal. It found that more than two-thirds of children rarely or never used latrines, and that a quarter of kids defecate in or near water,[51] releasing parasitic eggs as a result. Disease transmission is also common among adults who use rivers for bathing purposes following defecation. While some latrines are available, particularly in schools, many are not used or are deemed too dirty.

Hoping to reduce rates of schistosomiasis through infrastructure alone also neglects the importance of the river in people’s identities and livelihoods. “We could not imagine life without the existence of the river,” says Alassane dit Baye Ndiaye, a resident of Lampsar, a village upstream from Mbarigo. “Every family here has a fisherman, a farmer, or someone who is breeding animals. For all those activities you need water.” Standing near one of Lampsar village’s water access points, Ndiaye is surrounded by activity. A group of young boys splash joyfully; large silver platters bob just below the surface of the water waiting to be washed by a pair of girls; a mother prepares to bathe her infant son.

While Ndiaye says there are families who try to only use tap water, this ultimately isn’t realistic. “You can sensitize children and tell them to only use taps, but you can’t prevent them from coming here," Ndiaye says of the river. As if on cue, the gaggle of young boys shriek in a splashing frenzy. "Even if children do not come here they are obliged to go to the fields and help water the gardens, so they need to be in contact with water. Many people have no other choice."

Maguette Diop, the farmer from Maka Diama, has been infected with schistosomiasis twice. Both times he has had to purchase praziquantel treatment in the nearby village. He suspects he contracted the disease while in his rice field. Despite these suspicions, Diop wasn't able to change his behavior: "it couldn't prevent me from coming to work every day," he says.

Awa Diop, unrelated to Maguette, lives in Lampsar village with her nine children. She's tried to change the behavior of her kids since two of her daughters contracted schistosomiasis after what she suspects was a post-lunch bath. While she was able to afford the cost of praziquantel for her children, she says this might not always be the case. As a result, she's limited her kids access to the river, encouraging them instead to use the tap and well water on their property for chores. That means they could avoid all contact with the river—technically. "If they had the choice they would rather do laundry in the river since it's easier and cooler," Diop shrugs. And unlike tap water, the river is free. "With the river you don't need to collect water or change the water in your bucket. It's a bit complicated when they can't go there."

Tap and well water isn't an option for other families living in the Senegal River Basin, despite its proximity to Lac de Guiers. That lake is the most important freshwater reservoir in Senegal, and is the primary water source for Dakar, located 160 kilometers southwest of the lake. While Senegal's urban areas have water coverage and sanitation rates sitting at 93% and 89% respectively, this drops to 71% for water coverage and 43% for sanitation in rural areas.[52] These disparities put rural communities at a higher risk of waterborne diseases like schistosomiasis.

The socioeconomic barriers faced by families combined with the cost and logistical limitations of MDA campaigns mean actors battling schistosomiasis have had to turn their gaze in new directions. To The Upstream Alliance, that pluralization of 'directions' is key. Prawns could be the missing piece in a suite of solutions that address the complex layers of environmental, social, and economic factors.

Awa Diop stands with three of her nine children outside their home in Lampsar village.

More Prawns, Fewer Snails, Less Disease

[xxiii] Molluscicides are pesticides used to kill mollusks, including snails. While they often accomplish this mission, they can also affect other species.

Malacologist and Lampsar village resident Alassane dit Baye Ndiaye holds one of the snails that serves as an intermediate reservoir for the parasite causing schistosomiasis. Ndiaye has led sensitization and education workshops with community members, but notes that it can be difficult to ask people to stay away from water access points.

Before the advent of praziquantel, the public health community had no choice but to consider how changing environmental conditions could reduce or eliminate schistosomiasis. This approach has had success in a number of countries worldwide. Japan drained its wetlands, used chemical molluscicides[xxiii], and cemented its irrigation canals, reducing weeds and snail habitat as a result.[53] By 1994, schistosomiasis had been eliminated from the country. In the past century, countries and territories from Iran to Morocco to Puerto Rico have used snail control to completely eliminate the disease. Nearly a dozen others have used snail control methods to reduce prevalence of the disease by more than 90%.[54] The global evidence supports that environmental controls can also address schistosomiasis, rather than relying on drug administration alone.

For The Upstream Alliance focused on the Senegal River Basin, prawns are one potential environmental control method. With increased risk of schistosomiasis attributed to dammed river catchments, a decline in the native river prawn population, and an increase in snail hosts—as well as the limitations of MDA campaigns in high-risk regions like Senegal—the next step was for the team to prove that *reintroducing* wild river prawns into the could reduce the burden of disease.

To do that, the Stanford team joined with Espoir Pour La Santé (BRC EPLS), the Saint-Louis based biomedical research center, to run their first trial stocking of native prawns in villages. Scientific expertise came from both groups. The collaboration with EPLS was key in making it possible to test the prawn intervention in partnership with affected communities. EPLS had been working with Senegal River Basin villages for more than 20 years. “[EPLS] is not using the local population as a guinea pig, but they’re working with them to try and solve environmental and public health challenges that are taking a big toll on people locally. They really were our eyes and ears in the field,” says Dr. Giulio De Leo.

In 2012, the project reintroduced native *M. vollenhoveni* river prawns into Lampsar, one Senegal River Basin village. The prawns were put in a mesh net enclosure spread across the village water access point. The prawns were able to prey on snails that entered the enclosure. Another nearby village served as the control site for the study. The water point in this second village was not stocked with prawns, allowing researchers to compare and determine if the presence of prawns did, in fact, impact schistosomiasis transmission.

Over the course of the pilot study, thousands of snails were collected from the two village water access points, dissected, and analyzed for signs of infection from schistosomes. The study also looked at whether praziquantel, the drug used in MDA campaigns, could be more effective when combined with a prawn intervention. Midway through the study, participants were given two consecutive doses of praziquantel three weeks apart.

By the end of the pilot study, the abundance of infected snails had dropped by 80% in Lampsar, the prawn-stocked village.[55] Importantly, there were also fewer schistosome eggs found in the stool of villagers, meaning the intensity of infection in people had been reduced to a rate where praziquantel could cure in the long-run, rather than simply treat. There were more prawns, fewer snails, and less disease.

Expanded studies across 16 villages support that finding. An epidemiological model developed from those observations demonstrates that continued MDA campaigns *alongside* a prawn intervention offers the most rapid reduction in the burden of schistosomiasis.[56] This emphasizes The Upstream Alliance’s argument that it’s not about finding one right answer. “If you give the drug and control the environmental risks at the same time, whether that’s through improved WASH standards, molluscicides, or prawns, it’s going to be synergistic,” says Dr. Susanne Sokolow. “You’re balancing the equation so the worms you’re getting rid of are not being replaced rapidly. You end this perpetual cycle.”

↘ *Appendix 2: Figure 4A from 2019 Hoover et al paper*

In scientific principle, The Upstream Alliance has proven its reduced snails-reduced disease intervention in Senegal. But challenges still exist in getting enough prawns into the villages where they could affect the prevalence of disease. The adult prawns used in the pilot trials were either imported from Cameroon or fished out of nearby estuaries. What’s next for this planetary health intervention is determining how to get a steady, locally-sourced stock of prawns. To do that, The Upstream Alliance needs to focus on expanding a nascent industry.

Dr. Susanne Sokolow dissects snails in the Espoir Pour La Santé laboratory in Saint-Louis.

Putting Prawns Back on the Table

Re-introducing prawns to Senegal River Basin villages could have a positive impact on public health—and that's not all they could do. If sustainably managed, the prawns could restore the Senegal River's fishery which had been disrupted by the construction of the Diama Dam. The domestic breeding of prawns could also support the growth of the aquaculture industry, a priority for the Senegalese government. Finally, prawns could provide an important source of food and protein for people living in the region.[xxiv]

[xxiv] Aquaculture is an increasingly "popular" technique to combat poverty and food security challenges. Can you find global trends on what types of species predominately are fished, what countries predominate in the industry, and the benefits and challenges of various types (coastal, offshore) or species type (algae, shellfish, finfish)?

Senegal's aquaculture industry has grown steadily over the last decade, and production expanded by 46 fold between 2007 and 2016.[57] The growth in Senegalese aquaculture is consistent with global trends—especially important as marine fisheries decline worldwide.[58] Globally, the Food and Agriculture Organization of the United Nations (FAO) acknowledges that sustainable intensification of aquaculture could fill the gap of livelihood creation and food security. There's a long way to go.[xxv] As of 2016, sub-Saharan Africa contributed less than 1% to the global production of aquaculture.[59] Aquaculture is still a nascent sector in the region, and this figure is perhaps not surprising given the region's limitations in freshwater access, technology, governance, energy supply, and technical capacity.

[xxv] What are the negative consequences of the intensification of aquaculture?

Aquaculture and the Blue Economy

Aquaculture constitutes nearly half of the world's fish production and provides 53% of fish for human consumption.[60] Not limited to fish species, aquaculture production also involves the production mollusks, crustaceans, and aquatic plants and algae. In its 2018 State of the World Fisheries and Aquaculture Report, the FAO notes aquaculture is growing faster than any major food production sector worldwide. With the world's population expected to grow to 10 billion by 2050, sustainable intensification of aquaculture could be key in ensuring everyone has access to nutritious diets.

The majority of aquaculture production (90%) occurs in Asia. China is the leading producer, with production rates nearly four times higher than the world's second top producer, Indonesia. India, Vietnam, and Bangladesh round out the top five list in terms of aquaculture production.[61] While the earliest forms of aquaculture have been around since the Neolithic period (some estimate 4,000 B.C.), the industry is less than a century old on the African continent.[62]

There are a number of aquaculture methods, with operations taking place on land, in the ocean, and in freshwater. These techniques vary in productivity and environmental impact. For example, tilapia and shrimp are typically farmed using a pond method. If not treated and filtered, wastewater from these ponds can pollute the surrounding environment. This is what we saw in the Sri Lanka case study, where shrimps farmed using intensive pond aquaculture had a devastating effect on mangrove ecosystems. Contained systems typically have a lower environmental impact, as wastewater is managed and species are prevented from escaping into the surrounding ecosystem. SeaChoice outlines the many types of aquaculture methods on its website.

A group of men prepare to catch pond-grown prawns that are being bred as part of SIA breeding trials.

The fledgling hub of Senegal's prawn aquaculture industry is a large hatchery warehouse on the property of Gaston Berger University, a 30 minute drive from Saint-Louis. Papa Demba Ndao rolls back the large metal door to reveal the operation that, if and when it reaches capacity, could produce one million prawns a year for up to 1,000 villages in the Senegal River Basin. There's not much happening during this time of the year — Wjust Ndao and a colleague amidst the droning whir of one of the prawn tank filters.

Papa Demba Ndao holds two M. vollenhoveni prawns at the Station d'Innovation Aquacole (SIA) prawn hatchery. This is one of the locations where The Upstream Alliance has raised the prawns needed for its intervention, and it will continue to be a central hub for future research and development.

Ndao is an aquaculture engineer with *Station d'Innovation Aquacole* (SIA), an arm of The Upstream Alliance that runs this operation. The hatchery is headed by Nicolas Jouanard, Executive Board Member of The Upstream Alliance. He also works for Espoir Pour La Santé.

In the Senegal River Basin, this hatchery is an essential piece of infrastructure needed to make a prawn intervention possible. With the Diama Dam still impeding the ability for prawns to migrate up and downstream, aquaculturists need to imitate the reproduction cycle that existed naturally in the basin's environment. That requires the regular adjustment of water temperature and quality, salt water content, and food sources to ensure prawns and new larvae have the ideal conditions to survive and reproduce.

However, a key challenge has obstructed progress so far: *M. vollenhoveni*, the native African river prawn that The Upstream Alliance used for its pilot prawn interventions, has never been successfully domesticated.

Aquaculture ventures that currently exist in Senegal focus on tilapia and catfish, two fast-growing species that are low-maintenance when it comes to water quality and the food needed for survival. While tilapia and catfish can go from fingerling to fish in just six months, the process of prawn reproduction and raising larvae can take four months alone, with another minimum of seven months for the prawns to grow to their adult size.

"Prawns are very demanding and expensive because they need a lot of attention," says Ndao, scooping one up off the bottom of the tank and holding it in his hand. Its exoskeleton is delicate and soft to the touch—it has just gone through a molting stage. "Compare this prawn with catfish which can almost grow in a tank without air. That's not okay for prawns. You must have aeration and that needs electricity," Ndao says. Unfortunately, consistency of power supply isn't always a given in Senegal.

Unlike the adult M. vollenhoveni prawns that were used for The Upstream Alliance's pilot studies, the long-term sustainability of this intervention depends on raising prawns from larval stage. So far, SIA's breeding trials report a maximum of 5% survival during the larval stage. Successfully creating a new business venture would require at least 20% survival, and more developed aquaculture

ventures worldwide have 80% larval survival. "So we have a long way to go," says Dr. Susanne Sokolow. "The biology is challenging. We have the world's experts on it, both in Senegal and outside." One of the options is to potentially import an all-male cohort of a non-native freshwater prawn, *Macrobrachium rosenbergii*, in place of the native prawn (see textbox 5 for more information about the implications of this introduction).[xxvi]

[xxvi] Introducing non-native species might have negative consequences. What are they? What are some examples from around the world?

"Any species is complicated to breed in a context where the aquaculture sector is embryonic," adds Nicolas Jouanard, CEO of *Station d'Innovation Aquacole*. Successfully domesticating the prawns in the hatchery is one piece in the puzzle. The other is getting the adult prawns to survive the precarious conditions of village water access points. To-date, the ability for prawns to eat the snails and reduce disease has been challenged by the fact that the enclosure is not durable enough to survive the demanding environment of these water sites. The prawns either die or are collected before they can serve their public health purpose.

Next Steps for Prawn Progress

The Upstream Alliance has considered three options for raising the prawns needed to make any future venture a success. The first was the attempted domestication of *Macrobrachium vollenhovenii*, the native river prawn from West Africa. The team is looking at what comes next after pilot attempts to domesticate the prawn yielded a maximum of 5% survival rate during the larval rearing phase.

One option is to fish *M. vollenhovenii* prawns from estuaries in Senegal and other parts of West Africa, growing them to size in an outdoor pond before transporting them to villages or selling them to the market.

A third option may provide faster prawn growth and, as a result, more commercial and public health gain. That option involves introducing *Macrobrachium rosenbergii*, the variety of giant river prawn commonly used for aquaculture ventures worldwide. However, there's a catch: as a non-native species to Senegal there is the concern of how an alien species could affect existing biodiversity. The Upstream Alliance is working with Ben Gurion University in Israel to trial the introduction of transgender female prawns —changing the sex of *M. rosenbergii* from female to male ensures that only male offspring are produced. Laboratory tests have found no evidence of cross fertilization between the local and single-sex species.[63] This means introduced all-male prawns could be bred for aquaculture purposes without a risk of the population exploding out of control.

The Upstream Alliance received a permit from Senegal's Ministry of Environment in order to import *M. rosenbergii* from Israel. That importation of 15,000 *M. rosenbergii* post larvae will allow the team to begin to understand the challenges of growing the species using the resources and conditions available in Senegal.

"[The enclosure is] just a net, and everything can happen in the village. It's a public space and people do their laundry, dishes, and wash themselves and their animals. It's basically the worst place in terms of water quality," says Jouanard. "If I were a prawn I would also do everything I could to escape." Ultimately, he doesn't see the enclosure nets, which were designed for research purposes, as a translatable solution for prawn aquaculture.

Alassane dit Baye Ndiaye, a resident of Lampsar village, saw this problem firsthand. Ndiaye was responsible for maintaining the prawn enclosure in his village during The Upstream Alliance's pilot study. At first, he says there were some struggles with the enclosure because people didn't know its purpose, and kids and fishermen alike tried to cross the net to reach the other side of the river. By the end of the trial period, though, he says people in the village understood the role the prawn could play in their health. "Even when people saw a dead prawn they would come to my house and tell me. So they knew the importance of the prawns," Ndiaye says. "We would be pleased to again see them back in the village."

The Upstream Alliance is investigating ways to introduce prawns in villages without the need for a net enclosure. There's been discussion that adding prawns to rice paddy fields could provide a more hospitable environment while limiting the frequent public visits and household pollution of water access points. Another goal would be to encourage the company that manages the Diama Dam to construct a prawn ladder—a piece of infrastructure that would again allow prawns to naturally migrate up and down the river. The original species collapse may have been avoided had this cost-effective measure been taken in 1986.

The Upstream Alliance team has also calculated the prime stocking density of both the native *M. vollenhoveni* and the non-native *M. rosenbergii* prawns in order to effectively complement MDA campaigns. Those calculations include the optimal harvest time of prawns as well as the economic and food benefits each harvest would yield. For example, the non-native *M. rosenbergii* would be optimally harvested every 165 days, yielding about 1,560 prawns each time. That would bring in a 10-year average of US $5,400 with every harvest.[64] These economic calculations may seem outside the realm of The Upstream Alliance's original public health mission, but the team believes that if the prawn project is going to have sustainable long-term health effects there also need to be economic benefits.

Beyond the Ivory Tower: A Business Case for Prawns

In the future, The Upstream Alliance aspires to grow Station d'Innovation Aquacole (SIA) into a for-profit social enterprise. Social entrepreneurship fuses the for-profit mentality of the business world with the social impact more commonly associated with non-profits—demonstrating that financial success and positive impact are not mutually exclusive ambitions. Some dots need to be connected between The Upstream Alliance's current work and investors before that can happen.

SIA's business model is to use aquaculture to eliminate schistosomiasis in the Senegal River Basin. A percentage of the prawns domesticated at the SIA hatchery would go directly free-of-charge to villages where they could be stocked in nets, rice fields, or another location as a way to lessen the number of snails and, as proven by pilot studies, reduce schistosomiasis alongside strategic administration of praziquantel. Once prawns reach maturity, they could be harvested and sold or eaten by villagers, improving food security and providing a new livelihood opportunity.

The remaining prawns from the hatchery would be sold to high-end restaurants and hotels, with the revenue from those sales funding the continued restocking of prawns in Senegal River Basin villages. The sale of prawns to these restaurants and hotels means market demand would fund schistosomiasis interventions, allowing SIA to generate its own revenue and be financially sustainable.

If successful, this for-profit model would allow The Upstream Alliance to escape the time and focus constraints of traditional research grants or donor funding. Typically funded for just a few years, the short-term cycles of these forms of financing aren't necessarily well suited for the longer timeline needed to establish an aquaculture venture in an emerging market. Further, grants are often limited to one discipline—funding research related to human health *or* ecology *or* aquaculture. The Upstream Alliance is concerned this restricted scope may not be a good fit for the multidisciplinary nature of its work.

The feasibility study and business plan for SIA's for-profit model was developed by a team from the Middlebury Institute of International Studies at Monterey, California. The Upstream Alliance had reached out to the institute, wanting to prove to potential investors that they weren't only biologists, ecologists, international development practitioners, and epidemiologists


A prawn from the SIA facility.

—but savvy business people, too. They enlisted the help of Middlebury MBA students Tyler Higginson and Matthew Salyer, alongside economics professor Constantin Gurdgiev. Higginson visited Senegal to do market research and complete the feasibility study while Gurdgiev designed the venture's funding model.

While The Upstream Alliance has proof of concept for its health intervention, the business feasibility of the project is still only theoretical. This means the project remains in the research and development stage, and the business is looking for investment that could be used to start producing prawns and test the Minimum Viable Product (MVP) model. Gurdgiev estimates it would take US $60,000 to launch the MVP for the prawn venture. This start-up capital would fund upgrades to the current hatchery and allow for a first round of prawn breeding to fully assess market demand. Launching a new venture in addition to the existing pilot hatchery would require an additional ~$335,000 in capital expenditure. Based on Gurdgiev's market analysis, it would take 10 to 12 months from securing funding to produce the first commercially-viable batch of prawns.

According to Higginson's feasibility study, there is a market for prawns, both in Senegal River Basin villages and among high-end restaurants and hotels. "People are eager for it. They really enjoyed them in the past, almost to a nostalgic level, and they truly want the prawns," he says.

As well as supplying the market with an in-demand product, SIA's mission would also accomplish two desires of the Senegalese government: helping the country accomplish its priority of growing the aquaculture industry all while addressing a persisting public health concern. As a result, Higginson says SIA could possibly introduce something like a social impact bond—where the government pays the venture to expand the social impact side of its business (the stocking of prawns in villages to reduce schistosomiasis). "For example, the government could help subsidize the lost revenue of the prawns that go to impact rather than to market," Higginson says. "I think we will find a certain level of cooperation because we are addressing that social and health need."

Epilogue

In the end, SIA and The Upstream Alliance need more time. Time to import the all-male *M. rosenbergii* prawns. Time to see whether they can be domesticated in Senegal. Time to create a new solution for how the prawns should be stocked in villages. Time (and funding) to establish whether its for-profit model could be a success in the first place.

Those many waiting periods and paced progress illustrate what Dr. Giulio De Leo from Stanford says is one of the key learnings of planetary health interventions: the need for endurance and patience when dealing with projects and teams that are complex and multidisciplinary. He admits that this longer time scale can sometimes seem exasperating, particularly when dealing with challenges as urgent as the ones currently facing the world.

The story is far from finished in Senegal. Members of The Upstream Alliance team from the University of South Florida will be continuing their work looking into the effects of agricultural fertilizer on the spread of schistosomiasis. Generally, as well as through their work in Senegal, The Upstream Alliance team is hoping the planetary health community can develop a suite of tools so decision makers are better equipped to consider the environmental and public health implications of a development project—before it happens. Finally, they'd like to eventually take the prawn intervention on the road, applying it in countries like Brazil where there are increasing rates of schistosomiasis, native river prawns, and a more robust aquaculture industry.

It is tempting to simplify and point to prawns alone as the ideal intervention to eradicating schistosomiasis. But as The Upstream Alliance and those responding to the disease worldwide have learned, there is no one-size-fits-all answer. Instead, it takes a portfolio of tools developed from years of multidisciplinary expertise, consideration of the dynamic variables that affect a person's health, and sometimes, a business case to drive it all home. As Dr. Susanne Sokolow puts it: "complex problems, complex solutions."

Keeping Track of Who's Who

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Alassane dit Baye Ndiaye

Malacologist and resident of Lampsar village

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Economics professor at the Middlebury Institute for International Studies at Monterey; Member of the business development team for The Upstream Alliance

Dr. Gilles Riveau

CEO of Espoir Pour La Santé; Science Director (Senegal) with The Upstream Alliance

Matthew Salyer

Former MBA student at the Middlebury Institute for International Studies at Monterey; Member of the business development team for The Upstream Alliance

Nafissatou Diagne

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Awa Diop

Resident of Lampsar village

Maguette Diop

Farmer and resident of Maka Diama

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Acknowledgements

To everyone directly quoted in this case study: thank you for taking the time to speak with me about your work, lives, and livelihoods. Coordinating my time in Senegal would not have been possible without Nicolas Jouanard, Simon Senghor, and the entirety of the Espoir Pour La Santé team. To Andy Chamberlin, Dr. Giulio De Leo, and Dr. Susanne Sokolow: thanks for your work and for sharing many an adventurous truck or car ride. Today, I'm happy to consider you all friends. Constantin Gurdgiev, Tyler Higginson, and Matthew Salyer from Middlebury Institute for International Studies at Monterey helped with the financial section of this case study. Tapha was my star interpreter in the Senegal River Basin, and to him I extend the utmost thanks.

A water access point in Lampsar, one of the Senegal River Basin villages where The Upstream Alliance is working.

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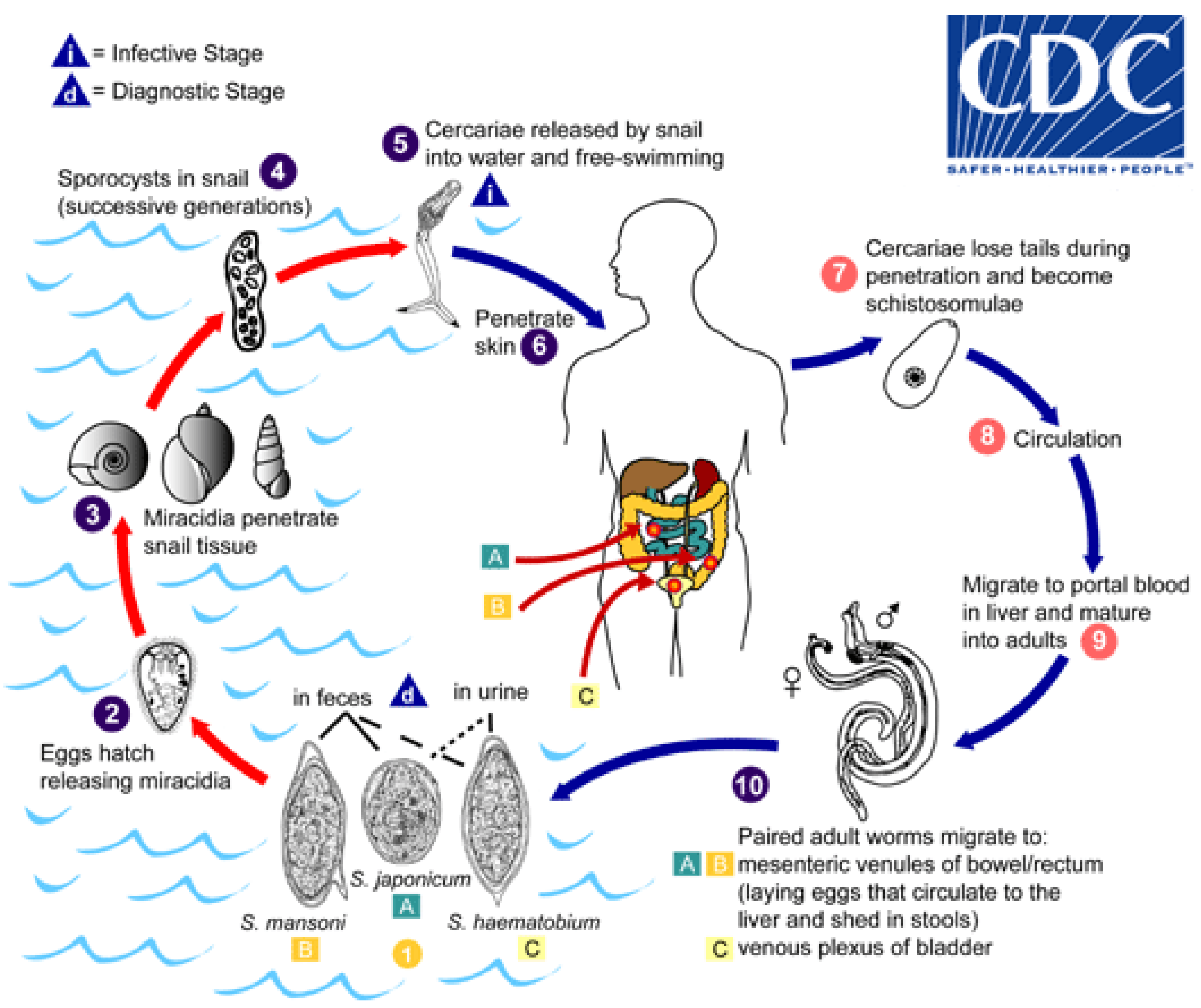
Appendix 1: CDC schistosomiasis diagram ↘ Back to page



Appendix 2: Figure 4A from 2019 Hoover et al paper ↘ Back to page