# Socio-Ecological System Impacts of Anthropogenic Pollution on New River Communities in Belize

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Abstract

Changes to the New River in northern Belize, Central America, including an annual eutrophication event near the river's primary urban setting, have had multiple impacts on New River communities. This mixed-method study examines perceptions of New River changes from forty-two resident interviews in twelve riverside communities using phenomenology and chi-square tests of independence methods. This study finds five categories of socio-ecological system (SES) impacts from anthropogenic pollution to residents; river pollution (exacerbated by drought conditions) impacts human health, livelihoods, environment, culture, and social justice. There are implications for community future uncertainty, powerlessness, and lack of trust in industry and government. Comparing zones in the study, the research found statistical significance in six factors. Pollution and other river changes were perceived to originate from a variety of sources, primarily industrial drainage. Government leadership, along with industry, agriculture, and community stakeholders, can facilitate solutions to safeguard the New River and its communities.

***Keywords:*** socio-ecological systems, Belize, eutrophication, pollution, health, climate change, livelihoods

# Impactos del sistema socioecológico de los antropogénicos contaminación en las comunidades de New River en Belice

Resumen

Los cambios en New River en el norte de Belice, Centroamérica, incluido un evento de eutrofización anual cerca del entorno urbano principal del río, tienen múltiples impactos en las comunidades de

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New River. Este estudio de método mixto examina las percepciones de los cambios de New River a partir de 42 entrevistas con residentes en doce comunidades ribereñas utilizando fenomenología y pruebas de chi-cuadrado de métodos de independencia. Este estudio encuentra cinco categorías de impactos del sistema socioecológico (SES) de la contaminación antropogénica a los residentes; La contaminación de los ríos (agravada por las condiciones de sequía) tiene impactos en la salud humana, los medios de vida, el medio ambiente, la cultura y la justicia social. Hay implicaciones para la futura incertidumbre, impotencia y falta de confianza de la comunidad en la industria y el gobierno. Al comparar zonas en el estudio, la investigación encontró significancia estadística en seis factores. Se percibió que la contaminación y otros cambios fluviales se originaron en una variedad de fuentes, principalmente drenaje industrial. El liderazgo del gobierno, junto con la industria, la agricultura y las partes interesadas de la comunidad, pueden facilitar soluciones para salvaguardar el New River y sus comunidades.

***Palabras clave:*** Sistemas socioecológicos, Belice, eutrofización, contaminación, salud, cambio climático, medios de vida

# 人类污染对伯利兹新河社区产生的社会–生态系统影响

## 摘要

中美洲伯利兹北部新河（New River）的变化，包括每年在靠近该河的主要城市范围出现的富营养化事件，对新河社区产生了多重影响。本研究使用混合方法—现象学研究方法和卡方独立性检验，分析在12个河岸社区进行的42次居民访谈中关于新河变化的感知。本研究发现，人类污染对居民造成的社会-生态系统（SES）影响分为五类，水污染（干旱情况下加剧）对人类健康、生计、环境、文化以及社会正义都产生了影响。研究发现对社区未来的不确定性、无力感、产业和政府的信任缺乏具有意义。通过比较不同区域，发现六个因素中存在统计学显著性。污染与其他河流变化被认为源自一系列来源，主要是工业废水。政府领导力和产业、农业以及社区利益攸关方能共同促进形成解决方案，保护新河及其社区。

关键词：社会-生态系统，伯利兹，富营养化，污染，健康，气候变化，生计

## Introduction

Communities are dependent upon healthy rivers and watersheds; any changes to the ecological condition of a river can have impacts on watershed communities (Parkes et al. 2010; Postel and Richter 2012). On the New River in northern Belize, there is an annual eutrophication event, exacerbated by ongoing drought conditions, in and near Orange Walk Town (the river's main urban setting). Multiple sources of anthropogenic pollution over the past decades have contributed to the eutrophication of the New River, including agricultural runoff, industrial drainage, and urban solid waste disposal (SACD 2017; Wu et al. 2000). This study examines New River resident perceptions about the causes and impacts of anthropogenic pollution. New River residents rely on the river for their well-being and livelihoods and are vulnerable to pollution impacts. The study finds five categories of socio-ecological system (SES) impacts from anthropogenic pollution to residents; river pollution (exacerbated by drought conditions) impacts human health, livelihoods, environment, culture, and social justice. There is a need to mitigate reasonably foreseeable pollution impacts and safeguard the future of the New River and its communities. Solutions and recommendations of this study are specific to future research, government leadership in pollution management practices, and the participation of community stakeholders (i.e., residents, business owners) as effective conduits for governance and management of the New River. The article has the following sections: Background (history, ecology, climate, pollution sources, eutrophication); Mixed methodology; Thematic results (systemic impacts of anthropogenic pollution); Limitations of the study; Discussion and Implications; Conclusion; and Recommendations.

## Background

### *Ecology and History of the New River*

In northern Belize, the New River is a slow-flowing tidal river from inland Belize to Chetumal Bay, a brackish estuarine system (Esselman and Boles 2001). Made of limestone bedrock (Esselman and Boles 2001), the New River watershed occurs within the Orange Walk and Corozal Districts of Belize (Figure 1). The river originates from the New River Lagoon near Lamanai Archaeological Reserve and flows north-northeasterly to Chetumal Bay.

Historically, the New River was a major trading route for the Maya. In the 1800s, British loggers used the river as means of transporting logs to the Caribbean Sea for loading onto ships for export to Europe (Dobson 1973). Currently, the New River attracts tourists as a major conduit to the Lamanai Archaeological Reserve; the river also provides a transportation route for the sugar factory barges to deliver sugar and molasses to cargo ships in the bay. The New River is also locally used for fishing, hunting, and recreational swimming and is a source of livelihoods for local fishermen, tour operators, and businesses.


***Figure 1.*** Map of Belize with approximate New River location (blue line), Guide to Belize, 2019.

## *Riparian Forests and Wildlife*

The New River watershed contains a variety of riparian vegetation including broadleaf forest, shrubland, savanna, and herbaceous swamp and mangrove; the watershed also includes agricultural lands and urban development (SACD 2017). Riparian forests in Belize are habitat for a variety of wildlife, including several bird species, Morelet's crocodile, Hickatee river turtle, and freshwater fish species (Meerman, Boomsma, and Arevalo 2015). However, there is an increasing rate of forest and biodiversity loss from natural and increasingly anthropogenic causes, namely the agriculture industries of banana, sugar cane, and citrus (Cherrington et al. 2012; Young 2008); pressures on rivers and forests also include climate change, pollution, degradation, and riparian and coastal development (Ruscalleda 2016; Young 2008; Young et al. 2006).

## *Climate Change*

Climate change, particularly lasting drought conditions and storm intensification, is a contributing factor to New River degradation. Since 2014, there has been an ongoing drought in the

Central American region (FAO 2017). In 2019, the drought was exacerbated by the El Niño–Southern Oscillation event, making rainfall forecasts unpredictable (NMSB 2019). Drought can both degrade riparian forests and result in less river water volume (Garssen, Verhoeven, and Soons 2014). Chemical runoff and other pollutants can be concentrated in a smaller volume of river water (E. Boles, personal communications, August 2019) which can have human health and wildlife impacts (Garssen, Verhoeven, and Soons 2014). Also, the intensification of storms and hurricanes contribute to river changes. For example, Hurricane Mitch in 1998 caused spill-over flooding of an aquaculture species (tilapia) from Crooked Tree lagoon to the New River watershed system; this allowed tilapia (an exotic species) to overtake local fish populations (Esselman, Schmitter-Soto, and Allan 2012).

## *Anthropogenic Pollution of the New River*

The New River has experienced anthropogenic pollution from agriculture, industry, and waste runoff from riverside communities (SACD 2017). Pollution can contribute to river eutrophication. The largest amount of chemical waste pollution in the New River is agricultural industry and on-farm pesticide runoff (SACD 2017).

**Agricultural runoff.** There are approximately 5,000 sugar cane farmers in northern Belize (ASR-BSI 2014). Most of the district relies on local cane farming, directly or indirectly, for their livelihoods. Agriculture chemical pollution reduces the water quality by impacting temperature, dissolved oxygen, and organic and inorganic compounds (SACD 2017). A continuous increase or accumulation of nutrients (i.e., nitrogen and phosphorus from agriculture fertilizers, discharge of wastewater, and sediment load) can exceed the capacity of a water system, triggering eutrophication changes that can result in more frequent fish kills, algal blooms, and health impacts on the communities (ENI 2016).

**Industrial pollution.** Large industries in Belize emit pollutants such as chemicals, sediment, nutrient enrichment, and metal pollution into river systems (Esselman and Boles 2001). Also, oils from machinery and barges can impact river systems. The Belize Sugar Industries (BSI) factory, located in Tower Hill village near Orange Walk Town, has been operational since 1967, processing sugar cane from local farmers into crystalline sugar and molasses (ASR-BSI 2014). This service contributes to 5 percent of the Belize's gross domestic product and 6 percent of its foreign exchange earnings (ASR-BSI 2014).

Industrial effluent from BSI contributes to the degradation of the New River (SACD 2017). In a study on "cleaner production" opportunities for BSI, factory chemicals used during cane processing at BSI move into the wastewater stream, then to the wastewater treatment plant, and then into the New River system (Chicas 2008, 10). This industry wastewater may contain sug-

ar, residual fertilizers, and herbicides from the milled cane. "Presumably, fertilizer and agrochemicals are reaching local water supplies" (Esselman and Boles 2001, 54). Also, in processing sugar cane, there is the release of hot water from boiler houses (Esselman and Boles 2001). Water temperatures at a thermal discharge point on the New River surpassed the prescribed levels in BSI's Environmental Compliance Plan (DOE 2016), particularly during cane grinding season (7NewsBelize 2019).

**Waste runoff from communities.** Waste disposal from riverside communities, both solid waste (garbage) and non-solid waste (sewage, wastewater), contributes to New River pollution. Solid waste management in Belize, including storm water runoff, is inadequate; urban areas of Belize produce approximately 130 tons of solid waste daily or 200,000 tons annually (Grauet et al. 2013; Young 2008). Based on census information, roughly a third of Belizeans "dispose of residential solid waste in environmentally harmful ways including dumping the waste on land, burning waste, or throwing waste in rivers, seas, or ponds" (Grauet et al. 2013, 15). When improperly treated and disposed, waste run-off can have negative impacts on coastal and watershed resources. Ineffective waste runoff management, combined with the practice of clearing riparian vegetation to the river edge, can allow pollutants to directly enter the river system, degrade water quality, and increase pollution and sedimentation (Chicas, Omine, and Ford 2016).

### *Eutrophication*

The New River has been experiencing annual eutrophication events of varying intensities for many years. Eutrophication is characterized by an excessive growth of algae and low (dissolved) oxygen in water, due in part to an increase of organic nutrients and pollutants (ENI 2016). Eutrophication is a natural process; however, human activity (cultural eutrophication) has accelerated the rate and intensity of the process through multiple sources, including: 1) agriculture, such as chemical fertilizers, manure, and aquaculture; 2) industry, such as nutrients, oils, and chemicals discharges; and 3) urban pollution, such as storm water runoff, septic tank leaching, and fossil fuel burning (Chislock et al. 2013; ENI 206; WRI 2019). Eutrophication severely reduces water quality and can have serious environmental, economic, and human health impacts, including surface algal growth (i.e., film), biodiversity loss (i.e., loss of fish, wildlife, and plant species), loss of tourism, sulfur-like odor and taste, and toxic ammonia and hydrogen sulfide levels (ENI 2016). The sulfur-like smell can be influenced by increases in water temperature and subsequent decreases in dissolved oxygen (Rajwa-Guligiewicz et al. 2015). During the time of this study (July 2019), a eutrophication event was occurring, with signs of fish kills, severe browning, and a surface film on the river and emission of a strong sulfur-like odor. In early September, 2019, La Inmaculada primary school, adjacent to the New River in Orange Walk Town, was closed for several days due to pollu-

tion-related complaints from students, including headache, nausea, and vomiting (BBN 2019).

### *Socio-Ecological Systems (SES)*

The primary theoretical framework used for this study is SES theory. SES studies investigate multiple perspectives and linkages among social, cultural, economic, ecological, governance, equity, and other factors. Ecological changes such as anthropogenic pollution in watersheds are systemic, cumulative, and intertwined with human systems (Molnar and Molnar 2000). Rivers and human communities are linked in a system where an impact on one part of the system—pollution of a river—can impact human systems, such as health and livelihoods (Drexler 2019). The systemic nature of this study necessitates systemic examination using an SES framework. Dr. Elinor Ostrom, a Nobel Prize-winning political economist, developed the concept of SES using a multi-level and multi-perspectival framework of linkages, drivers, interactions, and outcomes. SES involves adaptive resource management, inclusion of multiple stakeholders, collective action, self-organizing, and bottom-up (community-based) inclusion of resource planning and management (Olsson, Folke, and Berkes 2004, 75; Ostrom 2009; Parrott et al. 2012). This study examines the perceived relationships, barriers, and pathways between anthropogenic pollution causes and impacts and New River communities.

## Applied Research Methods

This study uses a mixed-method approach in which both quantitative and qualitative data are used. This study examines perceptions of New River changes from forty-two resident interviews in twelve riverside communities using phenomenology and chi-square tests of independence methods. Chi-square tests of independence were used to compare perception of river changes and impacts in three zones along the river. Phenomenology was used for deep descriptions and categorizing common lived experiences. Both methods allow for comparison and close examination of multiple impacting factors of river changes to New River communities. All interview questions and study protocols were approved by an Institutional Review Board; all interviews followed a voluntary and informed consent procedure. Interviews were audio-recorded for transcription and analysis purposes.

### *Quantitative Method*

Demographic data collected was summarized and examined for central tendencies (means), range, and dispersion (standard deviations). Using IBM SPSS Statistics 23 software, chi-square tests of independence were performed to compare sub-populations and communities regarding their perceptions of economic, health, environmental, and other changes and impacts on the New River across the three zones in this study.

### *Qualitative Methods*

Phenomenology and semi-structured interviews were used in this study to gather resident perceptions and describe and categorize common lived experiences regarding changes to the New River and their impacts on local communities. The phenomenological approach is multi-perspectival and systems-oriented to understand and describe common experiences by recognizing patterns, categories, and themes that emerge from interview data collected (Creswell 2013; Gall, Gall, and Borg 2007; Ravitch and Carl 2016). To identify emerging themes, categories, questions, or conceptual frameworks from the data, a combination of Strauss and Corbin (1994), Creswell (2013), LeCompte (2000), and Ravitch and Carl (2016) strategies of open (analytical), axial (reduction and clustering of categories), and selective coding (the intersection or integration of categories, or data synthesis) was used for the initial, intermediate and final data analysis and synthesis phases, respectively.

### *Setting and Participants of the Study*

The study area includes twelve New River "hot spot" communities identified in the New River Watershed Assessment as having a high potential for impact from pollution (SACD 2017). New River watershed communities are primarily farming communities, which have similar social, ecological, and economic conditions; also, they are dependent on various socio-ecological conditions such as climate variability, water quality, and markets (Drexler 2019). In the twelve communities (ten in Orange Walk District and two in Corozal District), forty-two residents were interviewed for this study in late July 2019 (Figure 2). For the purposes of the quantitative aspect of the study, New River communities were categorized into one of three zones: Upstream (San Carlos, Indian Church, Fireburn, Shipyard, Guinea Grass, and Tower Hill villages); Mid-River (Orange Walk Town, San Jose Palmar, and Trial Farm); and Downstream (San Estevan, Caledonia, and Libertad).

During the thirty-minute face-to-face interviews, participants were asked their historical knowledge and use of the river and their perceptions of changes to the river and any impacts on their families and communities. Households in each community were selected using a stratified random design. Participants selected to interview from each household were "purposive and prescribed from the start" (Goulding 2005, 302), as the study needed historical knowledge, use, and perceptions of the New River. Also, the study aimed to be gender-balanced, with a near-equal number of male and female participants interviewed. Participants were asked both survey questions (i.e., demographic, closed-ended questions) and open-ended questions, which allowed for rich description of river use and importance, SES impacts from pollution, and other perceptions.

### *Data Analysis and Synthesis*

During data analysis, the study used a multi-perspectival SES framework to


***Figure 2.*** Twelve New River communities in Upstream, Mid-River and Downstream zones.

find linkages between perceived factors. Previous exploratory studies in Belizean farming communities (Drexler 2017, 2019) provided guidance for using an SES framework and mixed-method approach. The qualitative analysis process uses LeCompte's (2000) five-step procedure and the S.P.E.E.C.H. tool (Drexler 2019), which aid in analyzing, coding, and categorizing data from interview transcripts. Major themes and categories from both quantitative and qualitative analyses are presented in the Results section.

## Results

Mixed-method results are presented from forty-two semi-structured face-to-face interviews of New River residents in northern Belize. The research finds four major thematic categories related to resident perceptions of the New River: 1) uses and importance of the New River to local communities; 2) ecological changes to the condition of the New River (including eutrophication); 3) anthropogenic (human-caused) changes to the New River, including pollution, resource overuse, and ineffective management; and 4) SES impacts from anthropogenic pollution on the New River, including impacts on health, livelihoods, the environment, and culture.

### *Descriptive statistics*

Demographic information is presented in Table 1. Nearly half (54 percent) of the study participants are female. The average household size is 5.2 fam-

ily members per household. The age range of the participants is twenty-two to eighty-two years old. Seventy-three percent of the participants had either no formal education or achieved up to primary school level, which is consistent with the 2010 country census report (SIB 2010). All participants except one had lived in their community ranging from ten to seventy-four years, with an average of 37 years living in the community.

**Table 1.** Characteristics of the sample of participants interviewed.

| | | | |
|---|---|---|---|
| **Sample size** | **N = 42** | Male = 19 | Female = 23 |
| **Zone** | Upstream = 17 | Mid-river = 13 | Downstream = 12 |
| **Age (years)** | Mean = 49 | Min = 22 | Max = 82 |
| **Household size** | Mean = 5.2 | Min = 1 | Max = 15 |
| **Years in living community** | Mean = 37.9 | Min = 10 | Max = 74 |
| **Education level** | None = 4, Incomplete primary = 6, Primary = 21, Incomplete secondary = 4, Secondary = 4, Associates = 3 | | |
| **Occupation** | Farming = 7, Business = 6, Housewife/Domestic = 17, Other = 8, Retired = 4 | | |

### *Uses and Importance of the New River to Local Communities*

Participants in this study perceived the New River is important as a source for 1) nostalgia, recreation, and celebration and 2) nutrition, income, agriculture, and security during scarcity. Historical uses of the New River are presented in Figure 3. Examining historical uses and importance of the New River creates a foundation for understanding changes and trends related to the present-day status of the New River.

**Nostalgia, recreation, and celebration.** Participants in all zones of the study stated the New River has had multiple historical uses and has nostalgic or sentimental importance. A sixty-nine-year-old man from Guinea Grass said: "The first Guinea Grass villagers used the river for everything." He stated:

> When I was a child and off from school for the summer, I used to go to the riverbank to entertain myself, to fish and to swim. There wasn't potable water then and so we would consume that water. That river provided for the first people to settle in Guinea Grass, but at that time there were no industries. It was a beautiful river; there were fish everywhere, it was clean. It was the best in all of Belize ...

A fifty-year-old woman from Orange Walk said: "My dad would take us (up-river) sometimes—to take a little boat ride up the river or down that side .... We had more animals: Turtles, croco-

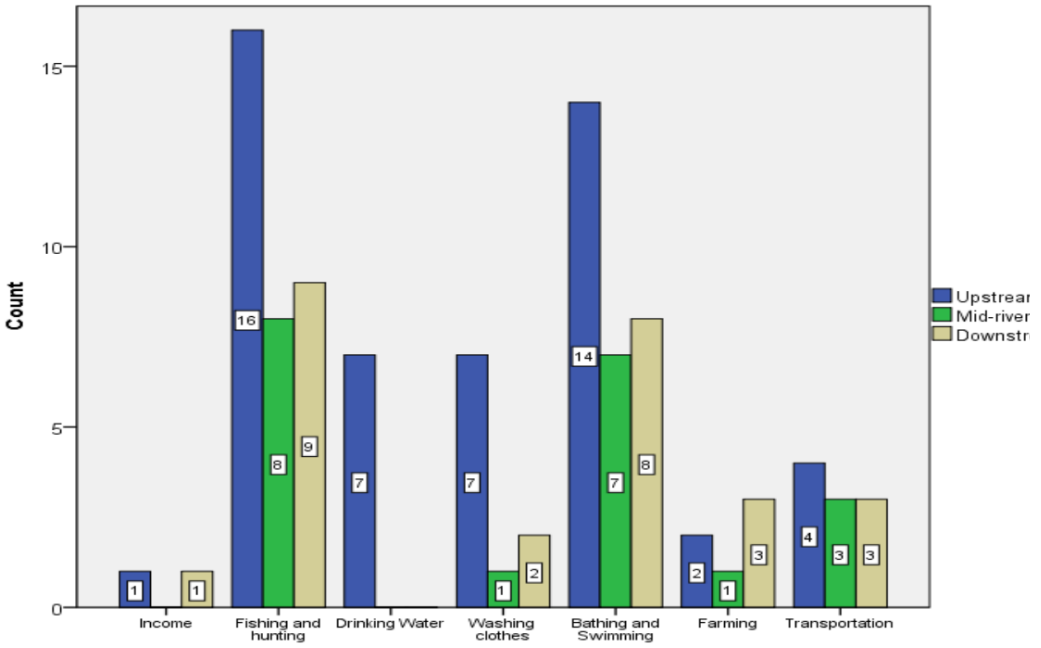


*Figure 3.* Historical uses and importance of the New River, comparison by zone.

dile, manatee." Other participants stated they use or have used the river for (recreational) "bathing and swimming" (69 percent). A 52-year-old woman from Caledonia said people from other villages come during "Easter weekend to have fun by the river."

**Nutrition, income, agriculture, and security during scarcity.** Participants stated the New River once provided a reliable source for fishing (both nutrition and income) and tourism income. A fifty-year-old woman from Orange Walk said the river has been a draw for tourists and birders. Today, however, there is low dependence on the New River for direct income (4.7 percent) of the participants interviewed. Seventy-nine percent (79 percent) of participants stated they once used the New River for "fishing and hunting." A sixty-nine-year-old man from San Estevan said fishing was easy, he used to bring in "sartas (lines) of fish" (for sale) and his children "grew up on fish." Other participants stated they remembered "bocona," "choc pinta," and other local fish being abundant in the past.

Participants identified present-day agricultural importance of the New River, including crop irrigation, extinguishing cane fires, mixing agrochemicals, and drinking water for cattle. A thirty-year-old woman from Shipyard (a Mennonite community) and a fifty-year-old woman from Guinea Grass both stated their cattle "drink water from the river" and when there is water shortage, "water is taken in drums for cattle to drink." A sixty-six-year-old farmer from Caledonia stated New River residents use the river water to mix agrochemicals to spray on sugarcane fields.

The New River has also been historically important for transportation and drinking water. A thirty-nine-year-old woman from Indian Church said they once used the New River for transportation to the village because there was no good roads back then. A fifty-three-year-old man from San Carlos said they used water from lagoon for drinking, but not since they got a water system two years ago; also, he said people used the river water to bathe and wash clothes before they built wells. Now, though, communities have reliable running water, electric systems, and good road access with public transportation, which has decreased reliance on the river over the years.

### *Ecological Changes to the Condition of the New River*

Participants in the study perceived several signs of ecological changes to the condition of the New River, including sign of eutrophication, especially in the last twenty years. Six ecological changes are highlighted in this study, including 1) climate change and drought; 2) river water condition—color, turbidity, and sulfur-like stench; 3) fish populations—decreased numbers of fish and different species); 4) wildlife abundance and behavior; and 5) riparian forest clearing and riverbank erosion. Three categories were shown to be statistically significant in comparing responses in three river zones (Figure 4). Ninety percent of respondents reported changes to "fish populations" in the river; 62 percent reported changes in other animals (i.e. turtles, crocodiles, mammals, etc.) and changes in "color and turbidity." Perceived changes were similar in the mid-river and downstream zones; changes that differed significantly across the zones were decreases in the number of birds (Chi square=11.611, p=.002), changes in the number of aquatic wildlife (Chi square=13.888, p=.008), changes in color and turbidity (Chi square=18.127, p=.001), and changes in algae/smell of the river (Chi square=13.450, p=.009).

**Climate change and drought.** Drought conditions, a lower river level, and dying riparian vegetation were perceived by participants in this study. A thirty-four-year-old woman from San Jose Palmar stated the climate is getting hotter with less rain. A fifty-one-year-old man from Tower Hill stated the river level has lowered by about three feet. A sixty-six-year-old farmer from Caledonia stated the drought is "a problem for the cane fields. It's August already, and the rains have not come." Storms and floods were also mentioned by participants in this study, particularly Hurricane Mitch in 1998. Impacts from the hurricane are discussed in "Changes in fish species."

**River water condition.** For the purposes of this study, changes to river water condition include color, turbidity, and a sulfur-like stench. Turbidity and color changes were perceived in the mid-river and downstream zones with descriptions such as: "greenish," "yellow," "blackened," "brown and hot," and "darker." Changes in algae and smell ("apesta el agua") were also perceived, usually occurring in June and July each

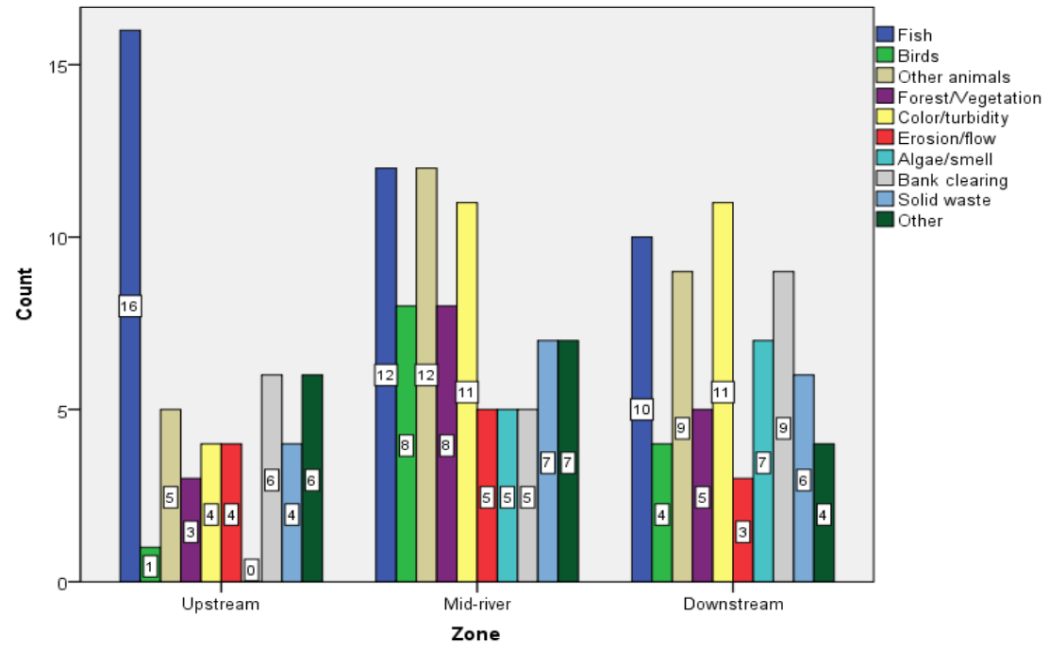


*Figure 4.* Perceived changes to New River by zone.

year. A twenty-nine-year-old man from Caledonia said: "When the bad waters ("aguas malas") come, that's a bad smell ... you can smell it. It's very strong." A thirty-eight-year-old man from San Jose Palmar said they are constantly smelling the bad odor and he thinks it could be "affecting people's lungs." A forty-seven-year-old woman from Orange Walk said "I don't go (to the river) ... but others yes. Maybe they can catch diarrhea and fever because of the (septic) stenches" while living close to the river.

**Changes in fish populations.** Ninety percent of respondents reported changes to "fish populations" in the river. Fish populations were perceived to be declining and being overtaken by tilapia since Hurricane Mitch (1998). Also, participants perceived more dead or dying fish, primarily in the mid-river and downstream zones, related to eutrophication. The word "dying" was stated fifteen times in the context of river fish.

Fish populations were perceived as "declining," "used to be numerous," "fewer," "scarce," or "finishing." A forty-three-year-old man stated there are "much lower numbers of fishes this year. (It) decreases more every year." A fifty-year-old woman from Orange Walk Town said: "At one time, there used to fish on this river ... there's not fish. No fish. Right now, I think even the little sardines you cannot see." A fifty-three-year-old man from San Carlos said there are "more tilapia in the lagoon" as a result of Hurricane Mitch flooding: "That brought tilapia from Crooked Tree, [and tilapia] feed on the juveniles of boconas (large-mouth bass)." A thirty-year-old man from Guinea Grass said the new fish species "banderuda"

came after the time of the hurricane and "chiwa" also moved into in the river. An eighty-two-year-old man in San Carlos village said tilapia "are taking over the river" and the native fish populations.

**Changes in wildlife abundance and behavior.** Several participants stated there is less wildlife overall, except for crocodiles. They perceived that there are fewer turtles; one participant explained this was due to people using more fishing nets. Terrestrial animals such as birds, peccary, monkeys, squirrels, deer, gibnut, armadillo, and iguana were also perceived to have declined; these declines were primarily perceived to be related to the dying off or clearing of riparian forests and vegetation (food sources and habitat for wildlife). A fifty-six-year-old man from Trial Farm said he does not see as many birds as before: "They used to sing a lot. It is as if they have gone somewhere else." Manatees were also perceived to have reduced in number. A sixty-six-year-old man from Caledonia said deer and gibnut were once hunted very close to the riverbank, but they are now scarce. A thirty-eight-year man from San Jose Palmar said a lot of wildlife "has left," he thinks due to river pollution. Participants perceived an increase in crocodile abundance and a change in behavior. A twenty-nine-year-old man from Caledonia perceived that due to the wetlands and lagoons drying due to drought, crocodiles have "moved to river." A fifty-year-old woman from Orange Walk Town said: "the crocodile are getting sick" (from pollution), "getting more aggressive," and coming "toward the people because they are hungry."

### *Anthropogenic (Human-Caused) Changes to the New River*

Anthropogenic (human-caused) changes to the New River were perceived by all participants interviewed for this study. For the purposes of this study, anthropogenic changes can be from human action or inaction. Participants of this study perceived eight major themes of anthropogenic changes to the New River: 1) industrial pollution, 2) BSI, 3) agriculture chemical pollution, 4) solid waste pollution, 5) overfishing by residents, 6) riparian forest clearing by residents, 7) riverbank erosion by industry and tour operators, and 8) ineffective governance and management (i.e., non-regulation or non-enforcement of pollution laws). Several participants connected the increase of chemical pollution with impacts of eutrophication.

Fifty-two percent of all participants interviewed for this study identified "industry" as the main cause of changes to the New River. Three themes were statistically significant (Figure 5) between the three study zones. In the mid-river and downstream zones of the study, participants made specific reference to BSI at Tower Hill. In the upstream zone, the main perceived human-caused changes were from overfishing and increased boat traffic (Chi square = 16.701, $p = 0.005$) and overfishing (Chi square = 13.600, $p = 0.001$).

**Industrial pollution.** Most participants in the study stated pollution of the New River was primarily caused by chemicals and oils from the industry or industries. Perceived signs of industrial pollution

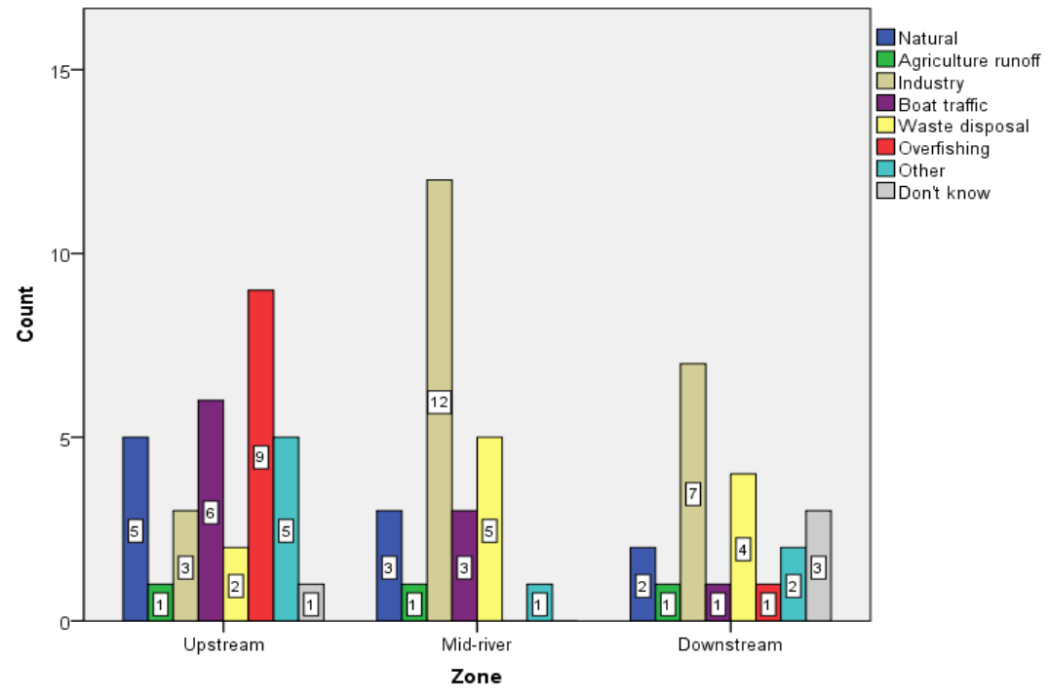


***Figure 5.*** Perceived Causes of River Changes to the New River, per zone.

were consistent with typical signs of eutrophication, including algae growth, a "milky-film" or scum on the river surface, a smell or stench (described as sulfur-like), dead fish, and other descriptions of what some participants called "aguas malas." Words used to describe this phenomenon were: "dirty," "smelly," "a stench," "darker," "greening," "yellow," "blacked," "milky," "scum," "a film," "a foam," "ruined," and "hot." A fifty-one-year-old man from Tower Hill said there is an increase in algae and a bad smell from the factory dumping. A fifty-year-old woman from Orange Walk Town said she avoids going to the river because she gets "too much headache. This morning I went early, before 7, and it was milky white ... I could see from the bend as far as my eye can see, it was like that." Industrial chemical pollution was perceived to be linked to acute or accumulated environmental health impacts (See "Socio-ecological Impacts").

Particularly in the mid-river and downstream zones, chemical pollution was perceived to be caused (in part or in full) by "industry," "factory," "chemicals," "BSI," and/or "oil from barges" used by the industry. BSI, a rum factory, a paper factory, three tortilla factories, and a sawmill exist in Orange Walk (mid-river zone of this study). A fifty-year-old woman from Orange Walk said from about fifteen years ago, "We started to notice a difference [due to] the pollution [in the water] ... even the plants in the river, they have like a dark, smelly stuff on the plants on the bottom; if you pull it up, like the water lilies, if you pull it up, there's a stench that you get from them. Rotten-y." Although most participants identified BSI, other

factories also were perceived to contribute to pollution. A sixty-six-year-old man from Caledonia said the rum factory has chemical runoff into the river. A forty-year-old woman from San Estevan said every year there is a poison and a smell "but (we) don't know who (caused it)."

**Belize Sugar Industry (BSI).** BSI was particulary perceived as a cause of chemical pollution in the New River. From interview data collected from forty-two residents, "BSI" was stated thirty-one times and "the factory" forty times in the context of industrial pollution and discharge. The word "chemicals" was stated in the context of chemical pollution from BSI or the factory (as opposed to agricultural chemicals). The word "poison(ed)" was stated twenty times; the word "contaminated" or "contamination" was stated seven times. A few participants, however, did not specify the source or origin of the chemical pollution.

The phenomenon of industrial pollution was not perceived to occur in the upstream zone of the study (i.e., San Carlos to Shipyard). A sixty-nine-year-old man in Guinea Grass said the New River from "Orange Walk to Lamanai [upstream], the water is perfect. It is clear and beautiful. It is fine to drink even now. But now, from where the industry is [between Tower Hill and Orange Walk] up to more north [downstream], the water is not good water." A sixty-nine-year-old man from San Estevan and a forty-seven-year-old woman from Tower Hill both stated before BSI, "the river was beautiful." A fifty-six-year-old man from Trial Farm and a seventy-four-year-old man from Orange Walk perceived that the industry "pollutes and ruins the water" and that the river is "ruined ever since the factory opened."

BSI tank-washing and thermal discharge were perceived as causes of river pollution. A fifty-one-year-old man from Tower Hill said: "When BSI factory is washed, it releases a stink substance or sweet substance that kills the fish." A thirty-four-year-old woman from San Jose Palmar said the tank washing effects fish: "When the BSI cleans out [later described as once a year], they do a chemical, and that's what you see: The fishes dying and floating in the water." A forty-seven-year-old woman from Tower Hill village said: "Right now the cane has finish ... they wash everything ... and everything goes flow in the river ... [and] the fish gone; you don't see fish." A fifty-two-year-old woman (and her husband) from Caledonia said whatever chemical is being disposed of, it "has to be a lot" to impact the river this much:

> Right now—supposedly like this time of year—(is) when the industry throws chemicals into the water. There is bad water that comes. When it comes like that, there are dead fish. It has to be bad water ... the company says that they don't know where it's coming from ... I think it's from the industry. Yes, yes. It has to be.

A thirty-six-year-old man from Libertad said: "I'm not really sure [but] I

think the problem is when they('re) working in the factory, sometimes they make a mistake and the bucket of oil throw [sic] in the river. It starts affecting the water ... it's just an accident, probably."

A BSI thermal discharge site upstream from Orange Walk town was identified by participants of this study as causing changes to the river. A fifty-year-old woman from Orange Walk said: "It's something in the water. I've taken pictures. The water gets very hot because of the waste that comes. I guess everybody says it's from the BSI factory. Because, around that areas (it) is worse." A thirty-four-year-old man from San Jose Palmar said: "When the water is hot, it has a funny smell ... you can know it's from the factory. It smells like the factory."

**Agriculture chemical pollution.** Although stated by only a few participants, agricultural chemical runoff was perceived to cause changes to the New River. In this study, the word "pesticides" was stated eleven times. Cane farmers who use pesticides and other agrochemicals were perceived to use (or overuse) agriculture chemicals. An eighty-two-year-old man from San Carlos said there is an increased use of pesticides; in the past, one liter of "veneno" (poison) was enough for cultivating tomatoes and now, he has to use more pesticide. He added the "thrip" insect (from Honduras) is attacking their plants and they have to use more pesticide, which is costly, and rotate use weekly because pests adapt to pesticides. A sixty-six-year-old man from Caledonia said "la maleza," a type of grass or weed, is difficult to kill with pesticides; he later said a lot of pesticides that are used end up in the river. A fifty-year-old woman from Orange Walk Town said: "The cane farmers use a lot of chemicals and pesticides. (It is in) what we eat." There were other participants who disagreed, stating farmers were not contributing to the pollution.

**Solid waste pollution.** Solid waste pollution (i.e., cans, bottles, plastic) and improper storm draining systems were perceived as sources of New River pollution. Solid waste was described as "garbage," "trash," "waste," "plastic" and/or "(styro)foam"; some stated that some people are careless, use the river as a "dumping area" and for waste disposal. A seventy-four-year-old man from Orange Walk said: "Everybody throws waste not only in the river and riverbanks, but also on the roadsides." A twenty-two-year-old woman from Libertad said: "People throw garbage during the celebrations especially—and the wind blows it into the river .... Some people no care; people just do what they want." A thirty-three-year-old woman from Trial Farm said people do not understand the importance of waste management: "Even one time, an official came to take photos of people throwing waste—but she refused because that (enforcing laws) could get her into trouble." A few participants disagreed, stating that community members do not pollute the river: They "keep it clean," primarily for tourism.

An improper stormwater drainage system in Orange Walk town was perceived as a solid waste pollution problem. The current system, managed

by the municipality, was described as allowing garbage to flow directly to the New River. A fifty-six-year-old man from Trial Farm said: "There is a lot solid waste on the streets and the river ... and town garbage exits the drain into the river." A fifty-year-old woman from Orange Walk said: "We have a lot of problem with [garbage]. Our worker has to keep constantly cleaning this side (i.e., the storm drainage)."

**Overfishing by residents.** Participants perceived residents were overfishing, including setting and using fishing nets. A sixty-year-old man from Indian Church said the river has changed due to overfishing. A few participants perceived Mennonite practices of overfishing were harming the river. A sixty-nine-year-old man from Guinea Grass village explained Mennonites [presumably from Shipyard, upstream] use a lot of nets so the fish "don't come like before." A sixty-six-year-old man from Caledonia said people catch fish during the mating season, which is a problem for future fish stocks; he has reported the problem to a natural resources management department, but he perceived that "no one cares."

**Riparian forest clearing by residents.** Riparian forest clearing was perceived by participants to cause changes to the New River. A forty-seven-year-old woman from Orange Walk said: "People cut down a lot of forest. I guess that's why things are happening now ... flooding." A fifty-two-year-old woman from Caledonia said there is less vegetation on the riverbanks because people cut down trees and burn, but do not replant. Primarily in the upstream zone, forest clearing to the riverbank was perceived to be due to Mennonite (Shipyard) activities; in the mid-river and downstream zones, forest clearing was attributed to sugar cane farming (also in SACD 2017).

**Riverbank erosion by industry and tour operators.** Riverbank erosion from industry barges and large, fast-moving tour boats was perceived by participants. A fifty-one-year-old man from Tower Hill said: "The banks are wider because of ... boats passing causing some trees to fall." A thirty-eight-year-old man from San Jose Palmar said the larger tour boats damage the riverbed throughout the river. A sixty-nine-year-old man in Guinea Grass said the river "has deteriorated a lot ... The boats that come have big motors that rip the bed of the river, where the fish are raised."

**Ineffective management and governance.** Participants perceived the local and national governments to be ineffective at informing, including, and responding to the public (i.e., with reported problems). Many perceived a lack of protection for the New River from pollution, both past and present. A forty-seven-year-old woman from Orange Walk said: "Government is not doing anything to help the situation"; she said if the government "would get strict in their laws, that (pollution) won't be happening." She added the government should: "Teach people that the river is very important (and) ... if that would be destroyed, we wouldn't have anything else" and "the community relies (on the river) ... that's all that we have, right?

The river." A seventy-seven-year-old woman from Libertad said she believes that the impacts from the factories have damaged the river since 1984, but that politicians have failed to protect the environment. A sixty-five-year-old man from San Estevan said there are chemicals released by the factory and there is no government nor department that has done anything about it: "All they do is a comedy." A fifty-year-old woman from Orange Walk said:

> A lot of people have tried (to help); they put it on the news ... the Environment Department comes and asks lot of questions and [they say] they are going to do something ... and nothing is done. And nothing will be done! Because who will remove the factory from there? No one. And they won't divert their waste to another place because it will be costly for them. And, you know ... the government, I guess, is on their side because the money is on that side.

At a local government level, a forty-nine-year-old woman from Caledonia said: "There is much that can be done but the local Village Council does not have motivation to do anything."

## Socio-Ecological System Impacts from Anthropogenic Pollution to the New River

There were several SES impacts from anthropogenic pollution to the New River perceived by all participants interviewed for this study. For the purposes of this study, SES impacts are multi-perspectival linkages perceived of a common lived experience: anthropogenic (human-caused) pollution to the New River. Four major themes of SES impacts to anthropogenic pollution are highlighted in this section, including 1) health impacts, 2) environmental impacts, 3) economic and livelihood impacts, and 4) cultural impacts. Industrial chemical pollution was perceived to have more acute or accumulated human health and environmental impacts; solid waste pollution, however, was perceived to be more of an eye sore or annoyance. Thirty-six percent of participants perceived health impacts from anthropogenic changes to the New River and 55 percent perceived economic impacts; these were perceived more in the mid-river and downstream zones of this study.

**Health impacts.** This theme refers to the perceived impacts from anthropogenic pollution on human health and safety, including a widely perceived skin rash, itchiness, and other health impacts. Although not quantitatively significant, there were important differences to perceived health impacts between zones; in the mid-river and downstream zones, 54 percent and 42 percent, respectively, stated health impacts from changes to the New River, whereas in upstream communities, only 18 percent perceived this impact. The word "rash(es)" was stated twenty-four times, "smell" was stated forty-seven times, "stench" was stated nineteen times, and headache was stated six times. Many participants used descriptive words such as "headache," "itch" (on skin), "sick," "cough,"

and "contaminated" during their interviews.

***Skin rash and itch.*** In all communities, except San Carlos and Indian Church, participants stated they, or someone they know, had an itch or rash after swimming or bathing in the New River. Most participants from Guinea Grass downstream connected this to the factory (versus agrochemical runoff). A seventy-four-year-old man from Orange Walk town said he once used the river for recreational swimming in the past, but there is no swimming now due to the factory releases. A sixty-nine-year-old man in Guinea Grass village (which is upstream from Orange Walk and the factories) said the river is "too contaminated due to the industry chemicals" and "when the tide comes [upstream from Orange Walk], everything from the industry comes over here, and many times it's not good to swim." A thirty-four-year-old woman from San Jose Palmar said she would not swim in the water right now because the: "Water is not good; it's got like poison chemical. It would give you rash." A sixty-nine-year-old man in Guinea Grass village said: "I don't go to swim but there are those that do and sometimes they get a 'comezon' (itch)." A forty-eight-year-old woman from Shipyard said the river causes a skin rash or "picazón" after swimming, but it "goes away after three days." A forty-seven-year-old woman from Tower Hill village said they do not swim in the river anymore "because a couple of years, my daughter wanted to go to bathe and she got like an itchness ... my nephew, them-the kids, they got rash. I told them it's the water ... they had to go to private doctor ... it's the water. It's the water."

***Other health impacts.*** Other perceived health impacts from anthropogenic pollution were related to consumption of fish, headaches, cough, swollen eyes, respiratory problems, allergies, and cancer. A sixty-three-year-old man from Orange Walk said that if the water is contaminated, then the fish are also "not good" to consume. A sixty-five-year-old man from San Estevan said he does not want to buy fish because he is afraid of eating it and getting sick. A thirty-three-year-old woman from Trial Farm said a Department of Health official advised her not to use the water for bathing or to eat the fish; she said they had stopped fishing due to the dead fish they were seeing in the river. A fifty-seven-year-old woman from Orange Walk said she has to give her child cough syrup and headache pills. A thirty-three-year-old woman from Trial Farm said people's eyes are swollen and reddish in color. A fifty-five-year-old woman from San Estevan said she has heard of some children with respiratory problems [allergies]. A fifty-year-old woman from Orange Walk said that missionary doctors and nurses have said "Orange Walk is a small place. And, there's a lot cancer cases here. A lot .... I don't know if it has something to do with [BSI factory chemicals] or maybe other things (i.e., farm chemicals)." Also, she said her employee "gets a sore throat. It's raspy ... he usually gets it only when he's around the river ... an allergy or something."

**Environmental impacts.** Most participants in this study perceived impacts

from anthropogenic pollution on the environment, especially fish and wildlife. A twenty-nine-year-old man from Caledonia described the surface film as appearing oily: "It shines like oil" and impacts the fish. Several participants linked pollution impact, specifically dying fish, with the annual "aguas malas" (bad water) caused by the factory, typically when the sugar cane season ends. Several participants described fish floating or dying at the river surface. A fifty-seven-year-old woman from Orange walk said: "Fish die off due to pollution, every year in June or July." Some participants stated there are fish kills due to "poisons in the water" and "when the factory releases poisons." A fifty-year-old woman from Orange Walk said the fish started disappearing about "15 years ago .... You can see the fish popping up in the side, you know they are grasping like they want to grasp for air." A sixty-nine-year-old man from San Estevan said you can't fish anymore because "the river is contaminated," "there's nothing" (no fish in it), and "right now we don't buy fish."

**Economic and livelihood impacts.** There were perceived impacts from anthropogenic pollution on the economy and livelihoods of New River communities. Participants in all study communities perceived an economic impact, including a) lower fish income, b).higher fishing expenses, and c) decreased tourism, primarily due to the sulfur stench of the river. Local fish were perceived as too small and/or scarce to sell. A twenty-nine-year-old man from Caledonia said there are "fewer fish each time" and before they used to sell a lot of fish, but now there are just a few. A sixty-six-year-old man from Caledonia said he and his son would go fishing and he would make his money that way, but now "there's no fish." Due to the drop in fish abundance, participants perceived that fish were more expensive to purchase; also, fishing expenses (e.g., fuel to travel farther upstream to fish) were perceived as higher. A sixty-three-year-old man from Orange Walk stated fish are more expensive because they are now brought in from Crooked Tree. A seventy-nine-year-old woman from Orange Walk Town stated: "The fish are (expensive), 6 dollar a pound, 7 dollar a pound." A sixty-six-year-old man from Caledonia said: "Now you need to go far and spend 2 to 3 hours to catch fish," whereas before, he could throw his line in and catch cabezona and pinta.

Tourism was perceived to be impacted by anthropogenic pollution. A thirty-eight-year-old man from San Jose Palmar said: "Tourists don't travel as much on the river because of the stench of the pollution." A forty-seven-year-old woman from Tower Hill said: "The smell and the water look ... dirty, and imagine they come to see something beautiful (and they see this)." A fifty-seven-year-old shop owner from Orange Walk said she loses local customers due to the bad smell in the area: "People no longer come to drink their coke and stay a while because of the smell."

**Cultural impacts and disconnection from the river.** There were perceived impacts from anthropogenic pollution on cultural or traditional uses of New

River communities, particularly fishing and recreational use. A thirty-eight-year-old man from San Jose Palmar said many people made a living from fishing and hunting, but it stopped due to pollution in the river. A forty-seven-year-old woman from Tower Hill said they used to go fishing, swimming near the toll bridge, and washing clothes in the river. A sixty-three-year-old man from Orange Walk said the last time he went to swim (near the toll bridge), his skin felt slimy and he had to go wash it off; he said: "The river seems to be useful only for the barges." A forty-year-old woman from San Estevan said she learned to swim on this river and that "young people don't swim (because it's) too dirty."

## Discussion and Implications

Multiple complex and cumulative SES impacts from river changes were found in this study, including ecological changes to the condition of the New River (including drought); anthropogenic (human-caused) changes to the New River (e.g., pollution, resource overuse, and ineffective management); and SES impacts from anthropogenic pollution to the New River, including impacts to health, livelihoods, environment, and culture. These results were further synthesized using selective coding, a simultaneous process of coding and analysis of data, each informing the other, where categories are related or conceptually linked in a systematic, multi-perspectival, and holistic way (Strauss and Corbin 1994). The intersections of these linkages are reference points to examine common phenomena, build an overall description, and inform targets for recommended practices (LeCompte 2000). The study finds there are social justice implications from these perceived impacts on the New River communities, including 1) uncertainty and powerlessness (from a lack of awareness and trust) and 2) future resource insecurity. The complex and cumulative SES impacts of changes to the New River necessitate government and stakeholder leadership to find system solutions.

### *Uncertainty and Powerlessness*

Participants interviewed perceived uncertainty and powerlessness regarding impacts from pollution from a) a lack of awareness and trust of industry (BSI) and government (i.e., on pollution impacts, ability to manage problems, protect the river and communities) and b) a lack of trust in community members to care for common resources. Participants perceived solutions were needed: the river "is just going from us and we can't do anything about it."

**Lack of awareness and trust of industry and government.** Overall, there were low levels of public awareness or knowledge of the impact of New River pollution. Sixty-nine percent of participants stated they did not perceive public education nor awareness of the New River's condition; their source of information was from news programs as opposed to information from the government or schools, for example. Overall, 67 percent of participants stated they were unaware of non-government organizations (NGOs) or other groups working to protect the river.

Participants perceived a lack of trust regarding the pollution problem and solutions from industry (e.g., BSI) and government to inform and protect the river and communities. Participants perceived ineffective government management. They recognized that the local economy is dependent upon BSI operation; thus, they stated, no one "stands up" to them. Others stated, "the government is on their (BSI) side" and wondered why the industries are not "being held by law to not pollute" the river. Others stated the pollution problem "could get worse if the government doesn't do anything."

**Lack of trust in community members.** Participants perceived a lack of trust in community members to care for the river as a common resource. Many participants described overuse of resources with descriptions such as "polluting," "overfishing," and "taking what they want." Mennonite residents from Shipyard were perceived to overfish, set fishing nets, and clear riparian vegetation to the river edge. Participants described some community members as careless, using "the river for waste disposal" and throwing garbage on shore or directly into the river.

### *Future Resource Insecurity*

All participants (except one) perceived an uncertain, conditional, or negative future for the New River. Forty-five percent of all participants perceived that the river's condition will get worse (77 percent in the mid-river, urban zone); 17 percent stated the river will—or hoped it would—remain the same. Participants who stated a negative future said there will be "less or no fish," the river will become "lower" (shallower), become more polluted, have a worse stench, be more cleared of riparian forests, have no wildlife, have less tourism, and have no swimming. Some stated "every day it gets worse," that it will not be usable, and that it will be "abandoned." One participant compared the New River to the Ohio river in the 1960s: "Because of the factories, the [Ohio] river ended up a ditch of [polluted] mud. And they said it was a beautiful river."

Participants also stated that the future condition of the river was conditional or dependent upon several factors. Thirty-six percent stated the New River's future was dependent on community and/or government action (i.e., whether people act soon to make improvements). Some participants stated that the future of the river depends on industry and government starting to care (about pollution levels and impacts), government making and enforcing stricter pollution laws, and their fellow community members taking care of common resources. One participant stated: "If [we] start taking care of the river and stop dumping, stop poisoning it, maybe it can be better."

## Conclusion

Communities are interdependent with the health of their rivers and watersheds—a *part of* the SES and *not apart from* it (Berkes and Folke 1998). Changes to the New River in northern Belize in recent decades, including an annual eutrophication event

near the river's primary urban setting, have multiple SES impacts on New River communities. This study finds five categories of SES impacts from anthropogenic pollution on residents; exacerbated by drought conditions, river pollution impacts human health, livelihoods, environment, culture, and social justice (i.e., powerlessness, lack of trust, resource insecurity). Comparing zones in the study, the research found statistical significance in changes to fish and wildlife, algal blooms, turbidity, sulfur-like stench, industrial pollution, and over-use (overfishing). Pollution and other river changes were perceived to originate from a variety of sources, including industrial drainage (primarily), solid waste disposal, chemical pollution from agriculture, and resource overuse (e.g., overfishing). Participants in this study perceived less overall use of the river, more impacts from pollution, and an uncertain or negative future of the New River such that there is a risk of further human disconnection, ecological decline, and eventual abandonment. As such, this complex SES problem necessitates systems solutions. Thus, it is important for government leadership and industry, agriculture, and community stakeholders to enable solutions to safeguard the New River and its communities.

## Recommendations

There are several recommendations for future research and practices regarding anthropogenic pollution and management of this and other rivers in Belize (Drexler and Castillo 2020). Many involve government leadership and prioritization of responsible use and solution-finding, including community participation by enabling and empowering local stakeholders (i.e., residents, business owners) as effective conduits for governance and management of the New River. Based on the findings of this study, the following recommendations could improve resource sustainability and security for the New River and its communities:

1. **Government of Belize (GOB) Department of Environment (DOE):** Develop a comprehensive New River Watershed Management Plan and Remediation Strategy to a) address the New River as a SES; b) examine anthropogenic changes and impacts, riparian forest management, agriculture, industry, and urban wastewater runoff impacts; c) develop mitigation and remediation strategies to include government, industry, agriculture, and urban planning; and d) facilitate community-based participatory action and identify community strengths (i.e., capital or assets), which foster sustainable and resilient communities by bringing more economic security, a healthier ecosystem, social inclusion, and a collective well-being (Flora, Flora and Gasteyer 2016).

2. **Belize DOE:** Work with local communities and NGOs to conduct comprehensive and comparative baseline studies of flora, fauna, water quality, and other indicators important for remediation strategies; employ a long-term study using

Geographic Information Systems; include cause-impact analyses that involve direct and indirect system impacts, spatial (wide-ranging) and temporal (long-term) and accumulated impacts factors (i.e., compounding impacts from Hurricane Mitch, increased tourism impact) to determine retrievable and irretrievable loss of the New River watershed.

3. **Belize DOE.** A) Develop new and/or more effective pollution regulations, laws, and enforcement for point source and non-point source pollution and mitigation. Utilize published recommendations from international and Caribbean water quality agencies regarding watershed pollution regulation, management, and remediation. B) Identify point source and non-point source pollution sources that contribute to New River eutrophication. Point source pollution (i.e., a discharge pipe) may be easier to target for mitigation compared to non-point sources, such as widespread agriculture chemical runoff.

4. **Belize DOE and New River Communities**: Include communities, local leaders, youth, business owners, and other stakeholders as partners in a participatory problem-solving process, working within social and cultural traditions (Drexler 2019). Promote community-based action initiatives, especially during the first five years of pollution remediation.

5. **BSI:** In a study on cleaner production opportunities for BSI (Chicas 2008), adopt Cleaner Production (CP) recommendations for BSI (and other) industrial operations.

6. **Department of Agriculture/Extension.** Develop a strategy for reducing agriculture chemical use and disposal in rivers, in coordination with the Pesticides Control Board and other agriculture entities in Belize. Extension can empower and encourage organizing of farmers to distribute and support adaptive, sustainable, food secure, and climate-smart farming strategies.

7. **Municipal and Village Governments.** Develop a strategy for improving sanitation services in urban and rural locations in Belize, in coordination with town councils using recommendations described in Grau et al. (2013).

8. **Department of Health, Ministry of Education, and New River Community Leaders.** Develop community-level pollution education and intervention programs; these can employ multiple behavior change models that target people at all educational levels. Adapt models that address environmental issues to include the "Environmental Citizenship Model," the "Model of Human Interaction with the Environment," and the "Value-Belief-Norm Theory of Environmetalism" (Akintunde 2017). Interventions must also use planning models, be multifaceted, and designed for goodness of fit for the New River context.

9. **FNR, Businesses, and Local NGOs.** Promote and monitor wise use and stewardship for New River resources. Natural resources (i.e., rivers, forests) are considered common resources, but used with "little consideration of the needs of others or of its sustainability"; more focus is needed on the "level of responsibility for its protection" (Frutos 2003, 4).

10. **Belize DOE and NGO Partner.** Establish a formal GOB-NGO partnership, i.e., with FNR, to manage improvement projects for the New River, coordinate research, collaborate with government and non-government entities (i.e., health, education, natural resources, agriculture), and implement educational campaigns within communities (Litschauer et al. 2018; Parkeset al. 2010). A locally-based NGO with a co-management agreement with the GOB will strengthen the DOE's ability to effectively manage the New River.

## Limitations of the Study

The timing of the study, during a noticeable river pollution event, was a limiting factor for this study, as the timing likely impacted participant responses. Two weeks prior to and during the study, the New River started experiencing a eutrophication event (i.e., a strong sulfur-like odor, surface film). Many participants were primed and eager to express perceived pollution changes, impacts of it, and blame for the polluted condition of the New River, particularly those in mid-river and downstream zones of the study. Specifically, many participants in the study blamed the sugar factory (BSI) for the river's polluted condition. Also, there was a sense of frustration with the lack of public information about the pollution and its impacts.

Eutrophication is nutrient and sediment overload caused by multiple sources: Agriculture, such as chemical fertilizers, manure, and aquaculture; industry, such as nutrients, oils, and chemicals discharges; and urban pollution, such as storm water runoff, septic tank leaching, and fossil fuel burning (Chislock et al. 2013; ENI 206; WRI 2019). In this study, however, participants perceived one primary cause: the sugar factory. Few participants perceived agricultural and urban discharges as contributing factors. Therefore, due to the omission of these and other factors in most interviews, the results of this study do not provide a complete picture of cause-impact linkages of anthropogenic pollution.

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## Author Biography and Acknowledgments

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