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Cultural Eutrophication Impacts on New River in Northern Belize: A Community Capitals Assessment

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Abstract

Watershed health and integrity are essential to human and ecosystem health and well-being. New River watershed communities in northern Belize, Central America are vulnerable to annual 'cultural eutrophication' - natural eutrophication exacerbated by human activity. Human-caused pollution from agriculture, septic effluent, and industrial drainage, in combination with extended drought and the slow flow of New River, has caused more frequent and prolonged periods of eutrophication. In this qualitative study, 42 New River residents were interviewed about river changes and impacts of eutrophication on their communities. Using the Community Capitals Framework to analyze resident perceptions, the study finds direct impacts from eutrophication on various sectors of society, namely environment, health, livelihoods, culture, and resource security. These impacts contribute to the vulnerability of New River watershed communities. The findings of this study can help policy makers and community leaders focus attention and resources to increase resilience of New River communities. Government policy and action recommendations are presented.

Keywords
New River; eutrophication; community capitals; watershed; health; livelihoods; resilience; Belize

1. Introduction

Healthy watersheds are essential to human and ecosystem well-being; any changes to rivers can directly impact watershed communities [1, 2]. In northern Belize, Central America, New River has experienced annual cultural eutrophication - natural eutrophication processes exacerbated by human activity [3, 4]. Human activity in New River has included agriculture, urbanization, logging, industry development, and tourism [5]. The accumulation of pollution from human activity, along with accelerated climate change, extended drought, and the slow flow of New River, has caused more frequent and prolonged periods of eutrophication [3-12]. According to the draft New River Management Plan, eutrophication creates a cycle of impact degrading the watershed which could cause a "permanent collapse of the New River ecosystem" ([5], p. 33). New River communities rely on the health of the watershed and can be vulnerable to eutrophication impacts on human health, environment, livelihoods, culture, and resource security.

Pollution from agriculture waste runoff, residential septic effluent, and industrial drainage have contributed to the already high nutrient content of the wetland-dominated New River for several decades [12]. It is important to identify pollution sources for reducing nutrient inputs and work with government and community members to mitigate impacts [5]. This study aims to examine New River resident perceptions of eutrophication (both causes and impacts) and identify how eutrophication can impact various sectors of society. Examining impacts to multiple sectors can inform recommendations for future research, management, and practice. This systems approach is especially useful for the Department of Environment (DOE) of the Government of Belize which is responsible "to enforce the Environmental Protection Act [and ensure] the prevention and control of environmental pollution, conservation, and management of natural resources" ([6], para. 1).

1.1 History and Ecology of New River Watershed

In northern Belize, New River is a slow-flowing tidal river occurring within Orange Walk and Corozal Districts (Figure 1). The river originates from New River Lagoon near Lamanai Archaeological Reserve and flows north northeasterly to Chetumal Bay, a brackish estuarine system [13]. The watershed includes multiple small agricultural communities as well as Orange Walk Town (population 15,300) [14]. New River supports a wide range of industrial, agricultural, and urban needs; New River sustains a tourism industry, providing income for families and building the local economy.

Figure 1 (a) Map of Belize with approximate New River location in northern Belize [15] and (b) a GoogleEarth image of the New River watershed communities in this study.

Historically, New River served as a major trading route for the Maya; New River was also a means of transporting logs in the 1800s by British loggers for loading onto to ships for export to Europe [16]. Also, New River used to provide a transportation route for sugar and molasses to reach Chetumal Bay [16]. The use of river tugboats and barges to transport sugar has been discontinued as sugar is now transported by trucks [5]. This change has reduced a significant impact to New River from tow boat props stirring up anaerobic sediments containing high amounts of ammonia; this is both toxic to many organisms and absorbs oxygen from the water column as it is converted to nitrite and nitrate [17]. Presently, New River attracts tourists and is a major conduit to Lamanai Archaeological Reserve. New River is locally used for fishing, hunting, and recreation as well as a primary source of income for local fishermen, tour operators, and businesses.

Ecologically, New River watershed contains a variety of riparian vegetation including broadleaf forest, shrubland, savanna, and herbaceous wetland and mangrove [9]. Rivers and lagoons adjacent to riparian forests in Belize are habitat for a variety of wildlife, including many bird species, Morelet's crocodile, Central American River Turtle, and freshwater fish species [18]. Riparian forests also serve as the filtration system of the landscape, capturing pollutants from water flowing off the landscape before it reaches New River. However, there is an increasing rate of forest and biodiversity loss from increasing anthropogenic causes, namely the industries of tourism, cattle, and agriculture (sugar cane, primarily) where forests are typically cleared to the river edge [19-21]. In addition to deforestation by agriculture, pressures on New River and riparian forests include climate change, pollution, landscape degradation, and riparian and coastal development [20, 22, 23].

1.2 Climate Change Impacts to New River

Although most directly tied to the United Nations Sustainable Development Goal #14, Life below water, impacts to a watershed can have multiple and cascading impacts to other sectors and SDGs, including Goals #3, Good health and well-being, #6, Clean water and sanitation, and #13, Climate

action [24], among others. Climate change, particularly long-term drought and storm intensification, contributes to New River degradation [25]. In New River, climate change causes conditions for eutrophication to occur. Lower water flow reduces dilution of pollutants resulting in increased concentrations of toxic pollutants and salinity; also, rising water temperatures increase stratification and algal growth, which increases cyanobacteria toxins, reducing dissolved oxygen which contributes to overall water quality degradation and possible human health and wildlife impacts [25-27].

Since 2014, there has been an ongoing dry season drought in the Central American region [28]. In 2019, the drought was exacerbated by the El Niño-Southern Oscillation event making rainfall forecasts unpredictable. Additionally, the intensification of storms and hurricanes have contributed to changes in fish populations. For example, Hurricane Mitch in 1998 flushed out tilapia ponds in Guatemala into the Belize River; also, flooding from tilapia farms in Crooked Tree lagoon has had spill-over to New River allowing for the introduction of tilapia (an exotic species) which negatively impacts local fish populations [26].

1.3 Eutrophication of New River

Eutrophication is characterized by excessive growth and die off of algae as well as low dissolved oxygen in water due in part to an increase of organic nutrients and pollutants [8]. Eutrophication, once resolved by finding and eliminating sources of phosphorus and nitrogen, is now on the increase in many rivers and other inland waters because the sources of these key nutrients are more diverse and more difficult to control [29]. This creates cumulative impacts fed by sources that may be both spatially and temporally distant from the impact site where water quality is severely reduced [30].

Eutrophication impacts human health in many parts of the world. Eutrophic conditions can contribute to formation of biofilms on the surface of the water, resulting from hydrophobic organic compounds released from the cell death of many organisms and polysaccharides [31]. The thick biofilm layers formed during eutrophic conditions and other times are often inhabited by many pathogenic bacteria. It is a health risk to get this film in your mouth, eyes and nose [32, 33]. Fine particles of this biofilm, airborne when carbon dioxide or methane bubbles rise through the film and burst, can be inhaled [33]. There are potentially serious health considerations for certain pollutants of New River. Communities along New River use the river as a daily source of drinking water, recreation, transport, and fishing; due to extensive land use around much of New River, there is "significant evidence of [negative] impacts on water quality" ([11], p. 13).

Eutrophication can often result in biodiversity loss (i.e., loss of fish, wildlife, and plant species), a sulfur odor and taste, and toxic ammonia and hydrogen sulfide levels [11, 34]. The sulfur-like smell can be influenced by factors including increases in water temperature and subsequent decreases in dissolved oxygen [34]. Algal blooms from eutrophication events can have serious environmental, economic, and human health impacts from planktonic algal growth and die off; for example, algal blooms can damage economic sectors such as tourism and fishing, lead to hypoxic conditions for fish and aquatic organisms, and can cause hazardous conditions for people and wildlife [5, 11, 12, 35].

1.4 Anthropogenic Sources of Pollution and Cultural Eutrophication of New River

Eutrophication is a natural process; however, human activity (e.g., pollution) accelerates the rate and intensity of eutrophication. This cultural eutrophication on New River, caused by decades of multiple-source anthropogenic pollution, has occurred from a combination of factors, including the following [3, 4, 7-10]:

- Agriculture waste runoff, such as aquaculture, and chemical (fertilizer) and manure runoff (e.g., cattle, sugar cane fertilizer),
- Industrial drainage, such as chemical, organic, and thermal discharges of nutrients, oils, and chemicals
- Residential septic effluent (e.g., sewage drainage, septic tank leaching), and
- Urban pollution, such as storm water runoff, septic tank leaching, hospital wastewater, and fossil fuel burning.

New River is regularly impacted by large amounts of sewage and agricultural runoff [4]. The biggest contributors to the high nutrient contents of the river are on-farm chemical waste runoff from cattle, sugar cane, and other agriculture as well as sewage-sourced nitrogen drainage [3, 7].

1.4.1 Agricultural Runoff and Accumulation

There are approximately 5,000 sugar cane farmers in northern Belize [36]. Most of the Orange Walk District relies on local cane farming, directly or indirectly, for their livelihoods. Agriculture chemical pollution reduces the water quality by impacting dissolved oxygen and organic and inorganic compounds [9]. 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 which can results in more frequent fish kills, algal blooms, and health impacts to the communities [37].

1.4.2 Industrial Pollution

Large industries in Belize emit pollutants such as chemicals, sediment, nutrient enrichment, metal pollution, and thermal discharge into river systems [12]. Also, oils from machinery and barges can impact river systems. Several industries occur in Orange Walk, including Belize Sugar Industries (BSI), a rum factory, a paper factory, three tortilla factories, and a sawmill [13]. The Belize Sugar Industries (BSI) factory, located in Tower Hill village just upstream from Orange Walk Town, has been operational since 1967, processing sugar cane from local farmers into crystalline sugar and molasses [36]. This service contributes to five percent of the Belize's gross domestic product and six percent of foreign exchange earnings [36].

In the past, industrial effluent from BSI has contributed to the degradation of New River [9]. In a study on "cleaner production" opportunities for BSI, factory chemicals used to clean equipment after the cane processing season used to move into the wastewater stream, then to its wastewater treatment plant, and then into New River system ([38], p. 10). This industry wastewater may have contained sugar, residual fertilizers, and herbicides from the milled cane and "presumably, fertilizer and agrochemicals [were] reaching local water supplies" ([13], p. 54). Up to 2019 with the notable eutrophication event, the BSI processing of sugar cane involved the release of hot water from boiler houses [13] such that water temperatures at a thermal discharge point on New River surpassed the

prescribed levels in BSI's Environmental Compliance Plan, particularly during cane grinding season [5, 39]. However, since then, the company has invested several million dollars into building a set of cooling towers to resolve this particular aspect (Ed Boles, personal communication, February 5, 2024).

1.4.3 Waste Runoff from Communities

Waste disposal from riverside communities, solid waste (refuse) and septic leaching, sewerage, and storm drainage, contribute to New River eutrophication. Solid and liquid waste management in Belize, including untreated storm water runoff, is inadequate [20, 40]. 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" ([27], p. 15). When improperly treated and disposed of, waste and wastewater can have negative impacts to watersheds. Ineffective solid waste and wastewater runoff management, combined with the agricultural practice of clearing riparian vegetation to the river edge, allow pollutants to directly enter the river system, degrade water quality, reduce dissolved oxygen, and increase sedimentation [21].

1.5 Community Capitals Framework

Community Capitals Framework (CCF) is used in this study to help categorize interview responses into dominant themes, find connections between themes, and achieve a better understanding of factors contributing to cultural eutrophication impacts to New River communities. CCF is a strengths-based, asset-driven framework which identifies system linkages, patterns, and relationships between multiple factors; CCF is useful for examining complex system issues (i.e., climate change adaptation, pollution impacts) [41-48]. CCF identifies community strengths and recognizes each community possesses resources, despite the conditions of poverty or marginalization, which can be used as the foundation of their resilience [44]. There are seven original Community Capitals developed by Flora and Flora [44], including: Natural, Cultural, Human, Social, Political, Financial, and Built Capitals (Figure 2).

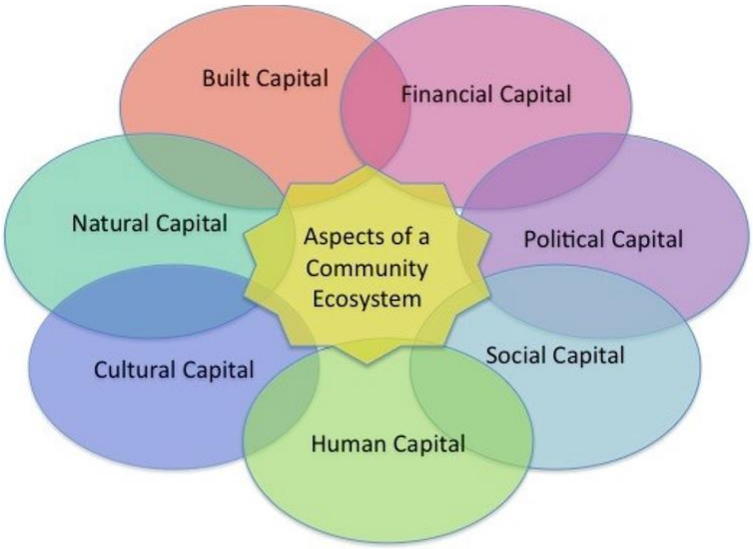

Figure 2 Original Community Capitals Framework model [46].

Each Community Capital can be linked within the New River watershed. For example, an impact to one part of the system-the loss or degradation of the river from pollution-can affect the human system, such as resource security and livelihoods [47, 49, 50]. A systems approach can assess multiple causal and impact factors and identify traits linked to resilient communities and thus more economic security, a healthier ecosystem, social inclusion, and collective well-being [51]. A strong set of Community Capitals can inform decision-makers where to focus attention and resources to increase community and watershed resilience [45, 50, 52-55]. Community leaders and stakeholders can elevate one or more or the weaker Capitals to bolster the whole watershed system [44, 45]. "When all the Capitals are working together - and when you don't ignore any of them - (a community) is more likely to have positive outcomes, such as heathy ecosystems, economic security for all, and social inclusion" (C. Flora, personal communication, November 15, 2018).

2. Methods and Study Setting

For this qualitative study, 42 residents in twelve New River communities were interviewed face-to-face to gauge perceptions of the causes and impacts of pollution and eutrophication on New River communities. The data for this study, published in 2020 [12], has been reexamined using the asset-driven Community Capitals Framework to assess five key Community Capitals - Heath, Environmental, Cultural, Financial, and Governance Capitals and how they are linked to the resilience of communities in the New River watershed.

Phenomenology and interviews are used in this study; a phenomenology approach allowed for deep description and thematic categorization of common lived experiences related to causes and impacts from anthropogenic pollution [56]. Phenomenology is a multi-perspectival and systems-oriented approach to understanding and describing common lived experiences by recognizing patterns, categories, and themes that emerge from interview data collected [56, 57-59]. Phenomenology also helps to "develop an understanding of complex issues that may not be immediately implicit" in participant responses ([60], p. 301). Using semi-structured interviews allows for participants to use their own words, descriptions, and stories [56-57, 61].

2.1 Data Sources

Semi-structured interviews were conducted in northern Belize's Orange Walk and Corozal Districts along New River watershed in July, 2019 to elicit perceptions of residents in twelve "hot spot" communities along New River. The hot spot communities were identified in the 2017 New River Watershed Assessment as having a high potential for impact from pollution [9, 12]. New River watershed communities are primarily farming communities which have similar socio-cultural, ecological, and economic conditions, such as climate variability, water quality, and markets [12]. The twelve communities were categorized into one of three zones, including:

- Upstream communities of San Carlos, Indian Church, Fireburn, Shipyard, Guinea Grass, and Tower Hill villages;
- Mid-river communities of Orange Walk Town, San Jose Palmar, and Trial Farm; and
- Downstream communities of San Estevan, Caledonia, and Libertad (Figure 3).

Figure 3 New River Communities, image from Google Earth.

Annual eutrophication events have been observed in mid-river and downstream communities.

2.2 Data Collection

Researchers selected households and conducted interviews using a rapid community assessment in each of the twelve New River communities. In each of the twelve communities visited, researchers first selected a central starting point and walked in the four cardinal directions to select the household interviews. Depending on the size, density, and layout of the community, researchers selected households using an interval (i.e., every third house) - providing for the best balance and distribution in the community - averaging approximately 4 interviews per community.

Once a household was selected, researchers asked to interview the 'head of the family/household' who then self-identified him or herself. Over half of the interview participants for this study who identified themselves as head of family/household are female. In Belize and other developing countries, women are considered head of the family/household if they are the primary or only parent responsible for raising and creating security for their family [62]. The subpopulation of head of family/household was purposive as it was critical to elicit household perspectives as families have direct knowledge of the conditions of New River. The researchers designed interview questions according to the *a priori* categories from the original Community Capitals Framework.

In total, 42 residents in twelve riverside communities were interviewed, including five participants in Libertad, four in Caledonia, four in San Estevan, four in Trial Farm, six in Orange Walk Town, four in San Jose Palmar, two in Tower Hill, four in Guinea Grass, four in Shipyard, two in Fireburn, two in Indian Church; and three in San Carlos. Two additional participants started interviews but could not complete the interview process and were thus not included in the study. Forty-two face-to-face interviews were conducted, each lasting approximately thirty minutes.

Participants were asked about their historical knowledge and use of the river as well as perceptions of river pollution and impacts to family and community.

Interviews were conducted in teams of two, including one local researcher who conducted interviews and translation when needed. The interview instrument contained brief demographic questions which also served as a warm-up for each interview as well as to help differentiate participants in the data collected. Primarily, the instrument contained a series of semi-structured questions according to the *a priori* community capitals categories; open-ended and semi-structured questions allow for participants to provide rich description of river use as well as perceived causes and impacts of pollution and eutrophication.

2.3 Data Analysis and Synthesis

To identify emerging themes, categories and linkages from the data, a combination of strategies was used for the data analysis and synthesis processes, included three coding phases as described in Strauss and Corbin [58], Stuckey [63], LeCompte [59] and Creswell [56]. These phases included open or analytical coding; axial (reduction); and selective coding, or integration of codes into dominant thematic categories [56-58, 60, 63-65].

Open coding was conducted using LeCompte's five-step procedure where responses were sorted into larger categories [59]. Both *a priori* (i.e., original community capitals categories) and *a posteriori* coding were used in this process. Axial coding was then conducted on a second review of interview transcripts, where themes and sub-themes were clustered into meaningful code-units. After open and axial coding were complete, a selective coding process was used to crystallize major thematic categories into dominant themes [56, 59, 60, 66]. The dominant themes were similar to the original Community Capitals Framework, with some modifications described in the Discussion section.

The selective coding (crystallization) process facilitated the finding of linkages, patterns, and relationships among major thematic categories [12, 58-59, 63-67]. Especially useful for a complex study with multiple and transdisciplinary factors, the process of crystallization uses a systematic, multi-perspectival, and holistic approach to blend data and produce linkages between categories [43, 58-59, 65, 67]. The linkages are reference points to examine common phenomena, build an overall description, and inform targets for recommendations for policies and practices [59].

All interview questions and study protocols were approved by the American Public University System's Institutional Review Board (IRB) in April, 2019. Interviews were conducted in English (English is the official language of Belize); however, at times, our local research counterparts provided translations for Belizean Creole and Spanish which are often used in conversation. All interviews were face-to-face and lasted approximately 30 minutes. All interviews followed a voluntary and informed consent procedure. Before starting the interview, researchers gave a brief explanation of the study and read the beginning of the consent form with each participant. When the participant agreed to continue with a verbal consent, researcher asked each participant to read and sign the informed consent before proceeding with the interview. Based on previous experiences, a verbal explanation (before requesting to sign a consent form) is culturally appropriate in Belize as signature paperwork is primarily related to purposes of legal or banking documents, for example. Responses from all interviews have and will be kept confidential. Interviews were audio-recorded for transcription and analysis purposes.

3. Results

Results from the 42 interviews for this study are presented in three parts:

- Section 3.1: Perceived causes of New River pollution and cultural eutrophication, including the perception of industrial pollution and agricultural runoff.
- Section 3.2: Perceived impacts from eutrophication on riverside communities, including environmental, human health, cultural, financial, and governance impacts.
- Section 3.3: Modified Community Capitals categories.

3.1 Perceived Causes of Pollution and Cultural Eutrophication to New River

Categories of eutrophication causes can include industrial discharges, agriculture chemical runoff, urban waste disposal, septic leaching, and ineffective governance and management, among others. For this study, 52% of respondents perceived the primary or only cause of eutrophication was due to discharges from the Belize Sugar Industries (BSI), a sugar processing factory upstream of Orange Walk Town. Some participants also perceived an increase of agriculture chemical runoff, solid waste disposal, riparian forest clearing/bank erosion, and/or ineffective governance and management (i.e., non-regulation or non-enforcement of pollution laws) as factors contributing to New River eutrophication.

3.1.1 Industrial Pollution

Industrial chemical pollution was perceived as a cause of eutrophication by most participants in this study. Most participants described chemicals and oils from 'industry', 'factory', 'chemicals', 'BSI', and/or 'oil from barges' used by industry. Despite several industries in Orange Walk, fifty-two (52%) of participants identified Belize Sugar Industries (BSI) at Tower Hill as the primary or only cause of anthropogenic pollution and eutrophication to New River. From interview data collected from 42 residents, "BSI" was stated 31 times and "the factory" (indicating BSI) was stated 40 times in the context of industrial pollution and discharge. Residents perceived signs of industrial pollution with statements such as "milky-film" on the river surface, a sulfur-like smell, dead fish, and other descriptions of "aguas malas".

The phenomenon of Industrial pollution was not perceived to occur upstream of the factory. A 69-year-old man in Guinea Grass said the water is clear and perfect upstream from Orange Walk Town, but "from where the industry is [between Tower Hill and Orange Walk] up to more north [downstream], the water is not good water." A 51-year-old man from Tower Hill said there is an increase in algae and a bad smell from the factory dumping. A 50-year-old woman from Orange Walk town stated eutrophication has been evident for the last 15 years. Also, she stated there is a thermal discharge site at BSI: "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 area (it) is worse." A 34-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".

3.1.2 Agriculture Chemical Runoff and Other Sources

Agricultural chemical runoff was perceived as a cause of pollution and eutrophication by a few participants of this study. Sugar cane farmers who use pesticides and other agrochemicals were

perceived to use (or overuse) agriculture chemicals. An 82-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 must use more pesticide. He added the 'thrip' insect (from Honduras) also necessitates more pesticide which is costly; he rotates use weekly because pests adapt to pesticides. A 66-year-old man from Caledonia said a lot of pesticides that are used end up in the river. There were other participants who disagreed, stating farmers were not contributing to the pollution.

3.1.3 Other Sources of New River Pollution

Other sources of anthropogenic pollution and/or exacerbating factors contributing to cultural eutrophication were perceived by participants in this study, including municipal storm drainage, solid waste disposal, and ineffective management and governance (i.e., inaction, non-regulation of pollutant runoff). One resident in Orange Walk stated "Our worker has to keep constantly cleaning the side (of the river). Everybody just don't *[sic]* care. I feel that the government is the only one that can educate people. They are saying and nothing is done." Other perceived sources of pollution included riparian forest clearing and riverbank erosion (i.e., from fast tour boats).

3.2 Perceived Impacts from New River Eutrophication on Communities

A priori categories from the original Community Capitals Framework were used to construct the interview questions. From interviews, participants identified multiple impacts from New River cultural eutrophication. Categories of impacts included environmental, health, culture, and other perceived impacts.

3.2.1 Environmental Impacts

Environmental impacts from New River eutrophication include fish, wildlife, and water quality. Participants in this study perceived environmental impacts from cultural eutrophication, especially to fish and wildlife (e.g., fish kills). Several participants linked pollution impact with the annual "aguas malas" perceived to occur after sugar cane season ends and BSI factory processing occurs. A 50-year-old woman from Orange Walk said eutrophication has occurred and fish started disappearing about 15 years ago. A 69-year-old man from San Estevan said there are no fish because "the river is contaminated".

3.2.2 Human Health Impacts

All participants in this study perceived health impacts from cultural eutrophication to New River.

Industrial chemical pollution was perceived to be linked to acute or accumulated environmental health impacts such as headache and rash. There were fewer perceived health impacts between upstream communities versus downstream (from the sugar factory (in Orange Walk Town). Health impacts included phrases such as "smell" or "stench", "rash(es)", "headache", "itch" (on skin), "sick", "cough", and "contaminated" during resident interviews. Other perceived health impacts included swollen eyes, respiratory problems, allergies, and cancer.

A 50-year-old woman from Orange Walk Town said she avoids going to the river because she gets "too much headache" and can see a milky-white film on the river "as far as my eye can see." Health impacts from pollution were also perceived as skin rash and itch. During the time of this

study (July, 2019), a eutrophication event was occurring, with signs of dead fish, severe browning of river water, thicker than normal surface film forming on the water's surface, and a strong sulfur odor. In early September, 2019, La Inmaculada Primary School in Orange Walk was closed for several days due to student complaints of eutrophication-related symptoms such as headache, nausea, and vomiting [27].

3.2.3 Cultural Impacts

Cultural impacts from New River eutrophication includes cultural traditions, historic use, and disconnection from the river. There were perceived impacts from cultural eutrophication on cultural or traditional uses of New River, particularly fishing and recreational use. Many residents used the river for fishing, hunting, swimming, washing clothes; however, the river is perceived as too polluted now for those activities. A 47-year-old woman from Tower Hill said her family used to wash clothes and go fishing and swimming near the toll bridge, but not anymore with the pollution present. Also, a 63-year-old man from Orange Walk no longer swims in the river because he said the last time he went, his skin felt slimy and he had to go wash it off. He added: "The river seems to be useful only for the barges" now. A 40-year-old woman from San Estevan said she learned to swim on this river and that "young people don't swim (because New River) is too dirty." Some participants predicted if eutrophication continues, there will be "less or no fish", the river will become "lower" (shallower), more polluted, a worse stench, less forested, less wildlife, and less tourism. Some stated it will not be usable and it will be "abandoned".

3.2.4 Financial Impacts

Financial impacts from New River eutrophication includes household expenses, tourism, fishing and other livelihoods. Fifty-five percent (55%) of participants interviewed for this study perceived economic and livelihood impacts from cultural eutrophication. One impact was lower fishing income as local fish were perceived as too small and/or scarce to sell. Also, expenses for fishing were perceived as higher, having to travel upstream or to a different river to fish. A 66-year-old man from Caledonia stated "there's no fish" now so his family has difficulty not having that income. Further, participants perceived fish were more expensive to purchase and there were more expenses (e.g., fuel needed to travel farther upstream) related to fishing. A 66-year-old man from Caledonia said: "Now you need to go far and spend two to three hours to catch fish" whereas before, he could throw his line in and catch cabezona and pinta. Eutrophication (e.g., health, financial). A 63-year-old man from Orange Walk stated people have to buy more expensive fish now because they are brought in from Crooked Tree village.

Another perceived financial impact was a decrease in tourism and businesses due to the white film and sulfur stench of New River. A 38-year-old man from San Jose Palmar said tourists don't want to visit the New River "because of the stench of the pollution." A 47-year-old woman from Tower Hill said tourists don't want to travel there because "the smell and the water look dirty." A 57-year-old shop owner from Orange Walk said she has lost local customers due to the bad smell in the area.

3.2.5 Governance Impacts

Governance impacts from New River eutrophication include New River management, regulatory monitoring, outreach, and security. Over a third of participants stated they lost faith in leaders to protect them and/or didn't feel confident in government leaders to address and solve the New River eutrophication issues. A 77-year-old woman from Libertad said politicians have failed to protect the environment. A 49-year-old woman from Caledonia said the "local Village Council does not have motivation to do anything." A 47-year-old woman from Orange Walk said the local and national government needs to act and have stricter laws; she added that government should "Teach people that the river is very important (and) ...if that would be destroyed, we wouldn't have anything else." Several participants stated a lack of government communication and public outreach such that residents had limited knowledge of the causes of pollution (i.e., agriculture and septic waste) and multiple impacts of eutrophication (e.g., health, financial). Some participants suggested government enforce stricter pollution laws and encourage community members to take care of New River as a common resource.

3.3 Modified Community Capitals Categories

Based on the results of this study on impact from eutrophication, Community Capitals categories were refined and modified from their original *a priori* model (Figure 3) to an *a posteriori* one (Figure 4). The modified Community Capital categories, individually and collectively, can be linked as part of a holistic system (described in section 1.5) where an impact to one part of the system-the degradation of the river from pollution, for example-can impact multiple aspects of the human system, such as resource security and livelihoods.

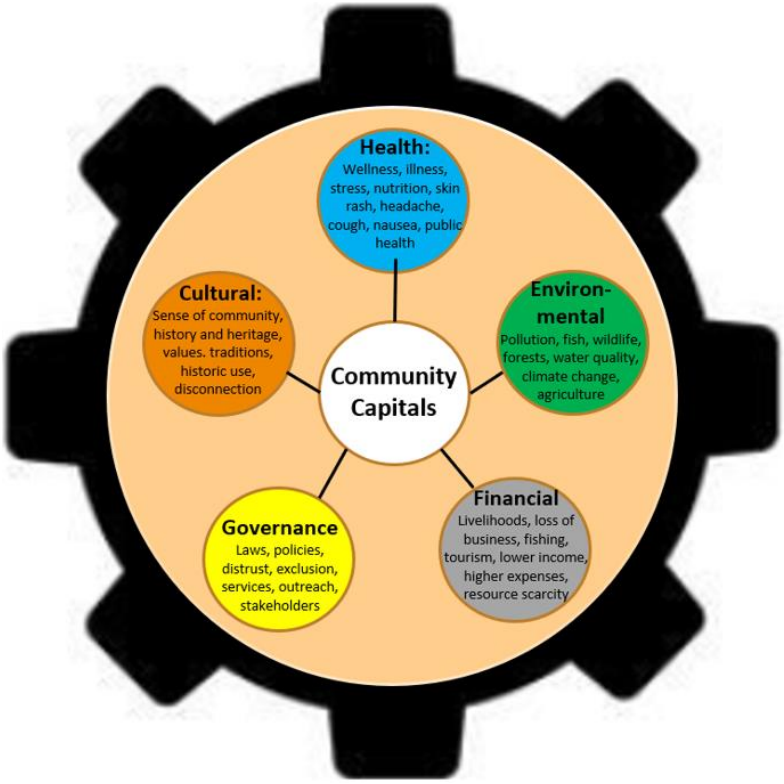

Figure 4 Modified (*a posteriori*) Community Capitals Categories.

4. Discussion

This study was the first known qualitative study of the New River which assesses community perceptions of causes and impacts of eutrophication on New River communities. Several quantitative (e.g., water quality, biodiversity) studies have been conducted on New River in the past which report New River is regularly impacted by an accumulation of nutrients from sewage and agricultural runoff; at times, this has exceeded the capacity of the New River water system, triggering eutrophication events which impact local communities [3, 4, 7, 9, 37]. The results of this study show a gap in public understanding about the multiple causes of eutrophication; most participants believe the sugar factory was the main or only cause of eutrophication. Few participants perceived other pollution sources as contributing factors; for example, no respondents perceived sewage or septic leaching as a factor and few participants perceived long-term agricultural runoff and solid waste disposal as factors of eutrophication. These pollution sources, combined with accelerating climate change, prolonged drought, and the slow movement of New River, have created conditions for cultural eutrophication, which has caused several impacts to the community.

Participants perceived five key Community Capital impacts from eutrophication on their community, including environmental, human health, cultural, financial, and governance impacts. These impacts connect to the resilience of New River and its communities as the Capitals are linked in system where an impact to one Capital can impact all others. For example, an impact on the environment (e.g., chemical pollution) is connected to impacts to health (i.e., rash, itch) and tourism livelihoods, governance, and so on. This study's findings are relevant for the holistic understanding of impacts from eutrophication on New River communities and to inform key recommendations for future policies, practices, and research to mitigate impacts and promote resilience of New River communities.

5. Conclusion

Based on the findings of this study, New River communities who rely on the health and integrity of their watershed are vulnerable to eutrophication events. Forty-two participants in this study identified direct impacts of New River cultural eutrophication on their communities. Using the Community Capitals Framework, impacts were categorized into five key Capitals: Environmental, human health, cultural, financial/livelihoods, and governance impacts. There are multiple implications; individually and collectively impacts to these key Capitals can be linked to the larger socio-ecological system and to the resilience of New River and its communities.

Attention to these Capitals can mitigate cultural eutrophication impacts and elevate health and resilience of New River watershed. Also, educating and empowering New River stakeholders about the array of causes and impacts of eutrophication to New River watershed is needed to mitigate reasonably foreseeable impacts and to restore watershed integrity. Recommendations for specific government and stakeholder policies, practices and research are provided in the following section. These actions can scale across multiple Capitals to mitigate cultural eutrophication impacts and protect New River watershed and community resilience into the future.

6. Recommendations for Policies, Practices, and Research

Recommendations are made for government and stakeholder policies, practices, and research to mitigate cultural eutrophication impacts and safeguard New River watershed ecosystems, human health, culture, and livelihoods. Holistic and systemic solutions are needed which identify capitals needing more resources and attention and which capitals could be amplified to create conditions for resilience in the New River watershed system. If adopted, the recommendations can inform policy and practice to mitigate impacts and promote resilience of New River communities.

Recommendations to elevate the Community Capitals include riparian reforestation and protection, youth and community outreach, drainage infrastructure improvements to agriculture, industry, small businesses (e.g., restaurants, bakeries), public health facilities (e.g., hospital, clinics), residential areas, and adoption of the pending New River Watershed Management Plan. The complex and cumulative impacts of cultural eutrophication necessitate system solutions from Government of Belize (GoB) and New River stakeholders including residents, farmers, business, industry, youth, elected officials.

Based on the findings of this study, a specific recommendation for GoB is the adoption and implementation of the New River Watershed Management Plan (NRWMP). The pending NRWMP is a comprehensive watershed management plan and remediation strategy to a) conduct ongoing research and address New River as a complex and multi-faceted watershed system; 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., capitals or assets) which foster sustainable and resilient communities by bringing more economic security, a healthier ecosystem, social inclusion, and a collective well-being [68]. Specific priorities should be protecting wetlands in New River watershed (as wetlands capture concentrated nutrients and convert them into less concentrated nutrients in the form of detritus that the system can handle); reducing and eliminating sewage input from Orange Walk and other communities; and using effective microorganisms (EM) to clean up sediments loaded with ammonia (i.e., forming EM into mud balls and dispersing them into heavy ammonia sediments).

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Author Contributions

Dr. Kristin Drexler is the principal investigator and primary author of this study. The study was originally published in 2020 [12] but reframed here contextualizing findings using the Community Capitals Framework. Dr. Ed Boles, an aquatic ecologist who has studied New River and coauthored the New River Management Plan, contributed significant portions of the Background.

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Competing Interests

The authors have declared that no competing interests exist. There was no external funding source and no outside role in the design of the study, in the collection, analyses, interpretation of data, in the writing of the manuscript, nor in the decision to publish the results.

Data Availability Statement

The data presented are available on request from the author. The data are not publicly available due to confidentiality and consent protocols related to audio recording of interviews; coding and categorizing of some transcribed responses are available.

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