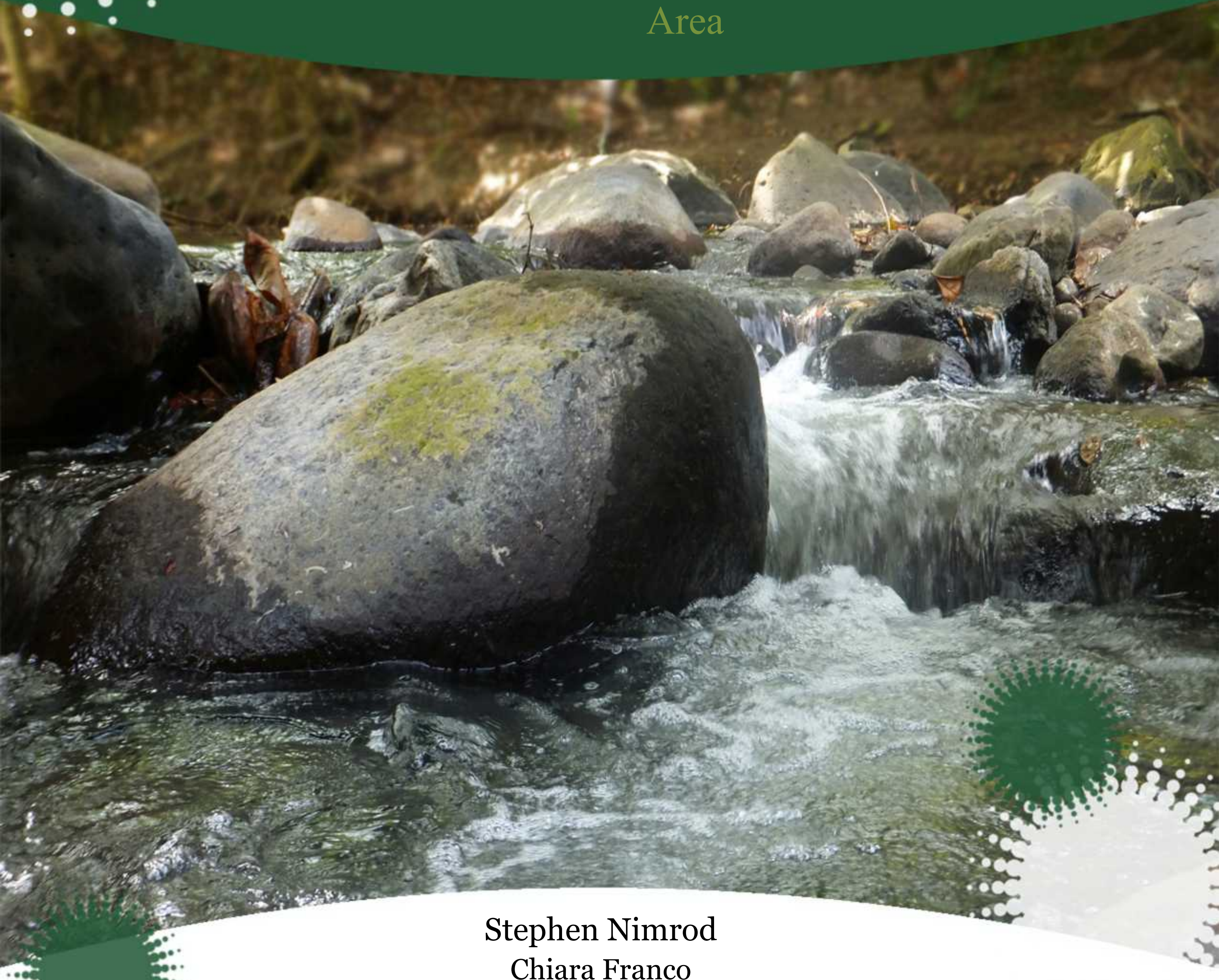
June 2013

Nutrient and Sediment Inputs of the Beausejour River

and the impacts it may have on the adjacent coral reef system in the Moliniere Beausejour Marine Protected Area



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Beausejour River © Stephen Nimrod

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1. Acknowledgements

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2 Executive Summary

In Grenada, a major problem facing coral reefs in the Moliniere Beausejour Marine Protected Area (MBMPA) is macroalgae overgrowth and their deleterious effects on corals. Reduced herbivory from overfishing and excess nutrients associated with pollution from land runoff have been implicated as factors causing significant increases in macroalgae cover on coral reefs.

Since the official launch of the MBMPA in September 2010, increases in the abundance and biomass of herbivorous fish on reefs in the protected area have been observed as a result of the implementation of some fishing restrictions. Nonetheless, this increase has had limited success in restricting macroalgae growth on coral reefs in the protected area thus far. This suggests that other factors such as dissolved nutrients in the water column might possibly be contributing to the proliferation of macroalgae on these reefs.

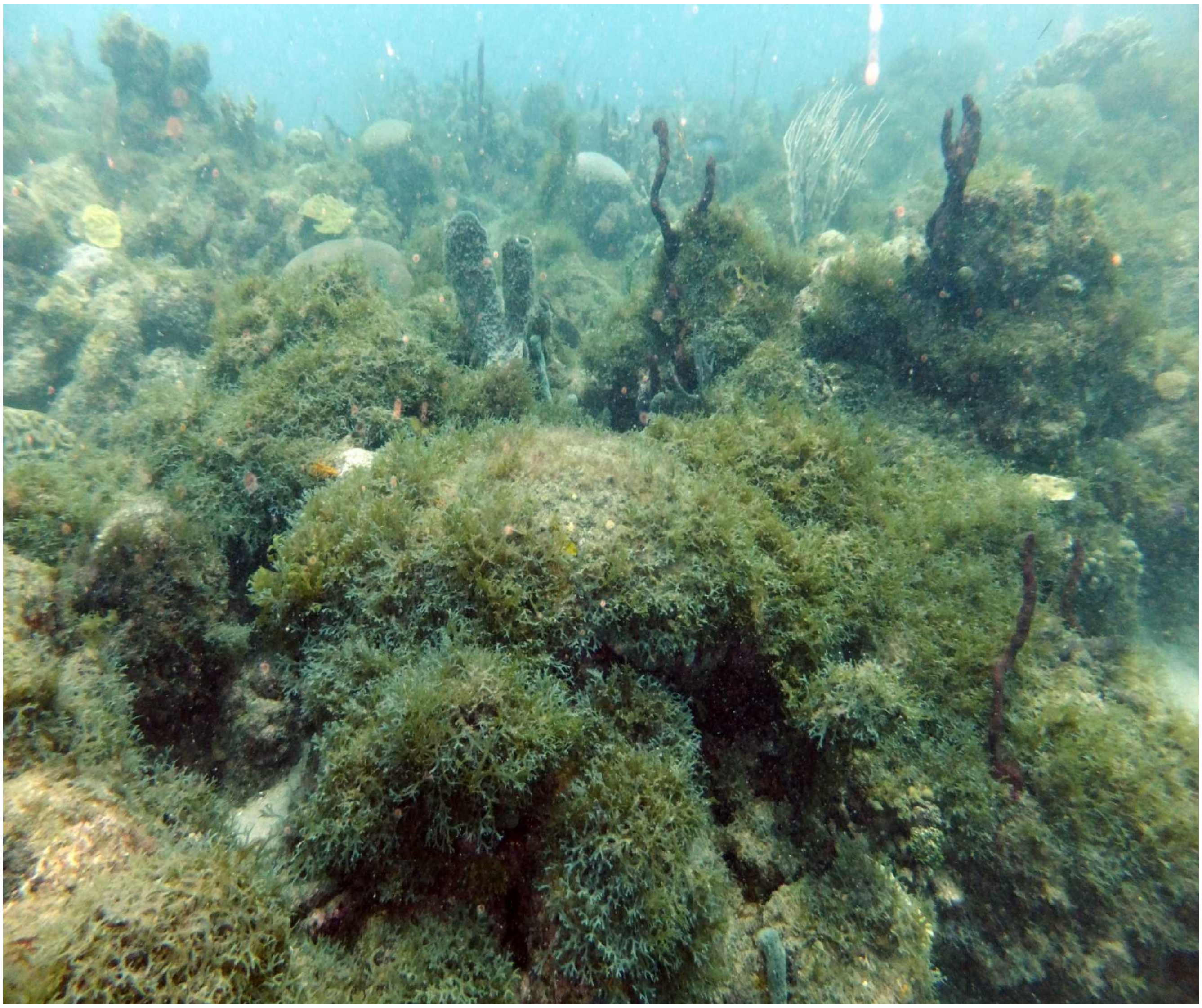
Runoff from rivers is a major source of nutrient and sediment inputs into the marine environment. There are a number of rivers with agricultural activities and human settlements in their catchment areas that discharge in close proximity to coral reefs in the MBMPA. Yet, very little is known about their contribution to nutrient inputs and the extent to which these inputs might be contributing to the problem of macroalgae overgrowth on coral reefs in the protected area.

This study sought to assess the impact that discharge coming from the Beausejour and other nearby rivers might be having on adjacent coral reefs. Chemical analyses were conducted on marine and river samples to assess nutrient levels, while sediment traps were deployed to assess sedimentation rates on adjacent coral reefs.

Key findings:

- Several of the sites sampled had remarkably high nutrient concentrations.
- Mean percentage cover of macroalgae on sampled coral reefs were very high
- A sedimentation gradient associated with the Beausejour River mouth was observed.
- The sources of inputs of sediments and nutrients into the Beausejour River were mainly related to agriculture, land use and domestic activities.

This study provides the first data set on nutrients and sediment loading for the protected area and will facilitate further comparison for future studies. More importantly, this study will inform management action aimed at reducing and eliminating as many land-based stressors as possible to increase reef resilience and improve coral health. Through the implementation and enforcement of best agricultural practices, improved sanitation facilities and education, these inputs of sediment and nutrients can be substantially reduced.



A section of coral reef in the Moliniere-Beausejour Marine Protected Area (MBMPA) close to the mouth of the Beausejour River.

Photo © Stephen Nimrod

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3 | Introduction

Beausejour River
Photography by Stephen Numrod

Introduction

Globally, coral reefs continue to decline due to a number of natural and anthropogenic factors (Hughes 1994; Gardner et al. 2003; Pandolfi et al. 2003; Fabricius 2005; Paddack & Cowen 2006; Hughes et al. 2007). In the Caribbean, many coral reefs have undergone what is now commonly referred to as a “phase shift”, whereby reefs moved from a coral dominated state to an algal dominated state (Huges 1994). In Grenada a major problem facing coral reefs in the Moliniere Beausejour Marine Protected Area (MBMPA) is macroalgae overgrowth, which can have deleterious effects on corals. These effects include outcompeting corals for space, inhibiting coral recruitment and blocking-out sunlight for photosynthesis, among others (McCook et al. 2001; Lirman 2001; Jompa & McCook 2002; Fabricius 2005; Mumby et al. 2005; Littler et al. 2006; Box & Mumby 2007; DeGeorges 2010; Smith et al. 2010).

Additionally, algal dominated reefs represent a threat to coral reef biodiversity and ecosystem functioning (Lettler et al. 2006; Burkepile & Hay 2006; Dailer et al. 2010; Most 2012). While primary production is an important component of food webs on coral reefs, significant increases in algae abundance can drastically alter reef processes, which can have profound effects on higher trophic levels (Most 2012). Reduced herbivory as a result of overfishing (Hughes 1994; Jackson et al. 2001; Pandolfi et al. 2003) and excess nutrients associated with pollution from land runoff (Pastorok & Bilyard 1985; Bell 1992; LaPointe 1997) have been implicated as factors causing significant increases in macroalgae cover on coral reefs.

The Moliniere-Beausejour Marine Protected Area (MBMPA) was officially launched in September 2010 with the commencement of active management and enforcement of management regulations. These regulations included some restrictions on fishing aimed at increasing herbivorous fish populations on reefs in the Protected Area. Since the implementation of these fishing restrictions, some increases in abundance and biomass of herbivorous fish on reefs in the protected area have been observed *(S.H.S. Nimrod Personal Observations Anecdotal)*. Nonetheless, the increases observed has had limited success in restricting macroalgae growth on coral reefs in the area thus far. The current herbivore population in the MBMPA appears to be inadequate, as macroalgae on those reefs appears to be growing at a much faster rate than the current herbivorous fish population can successfully graze down. This suggests that other factors such as dissolved nutrients in the water column might possibly be contributing to proliferating macrolgae growth on those reefs. Houk et al. (2010) showed that algal dominated reefs that had increased herbivory with a decrease in nutrients recovered more rapidly compared to reefs with increased herbivory but no decrease in nutrients. Smith et al. (2010) also highlighted that increasing herbivore populations on degraded reefs may be an effective strategy for coral-algal phase shifts, but is most effective in the absence of other stressors such as nutrient pollution.

There is considerable debate among scientists regarding the extent to which bottom-up (LaPointe 1999) and top down (Huges et al. 1999) factors influence macroalgae abundance and biomass on reefs. It is highly unlikely that a single environmental or ecological factor is responsible for problems like algal overgrowth on coral reefs, but rather, a combination of factors. Various stressors such as overfishing, pollution and climate may interact in complex ways to reduce coral cover and increase macroalgae cover on reefs (Rasher et al. 2011). The MBMPA authority therefore recognizes that there is an urgent need to consider bottom-up factors such as excess nutrients in the water column to compliment top-down control measures already implemented to reduce macroalgae. In so doing, the MBMPA will be essentially moving towards adopting a holistic "ridge to reef" approach to reducing and eliminating as many stresses and threats to coral reefs in the MBMPA as possible. This approach will eventually help to increase reef resilience and improve coral health.

Runoff from rivers is a major source of nutrient and sediment inputs into the marine environment. These inputs can increase macroalgae cover, smother corals and subsequently degrade coral reefs (Fabricius 2005). Agriculture, urbanization, deforestation and other land-use activities are some of the main contributors to increased levels of sedimentation and nutrients entering rivers and streams in tropical coastal areas (West & Van Woski 2001). There are a number of rivers with agricultural activities and human settlements in their catchment areas that discharge in close proximity to coral reefs in the MBMPA. Yet, very little is known about their contribution to nutrient inputs and the extent to which these inputs might be contributing to the problem of macroalgae overgrowth on coral reefs in the protected area. Some residences, tour operators and other users of the MBMPA have also expressed concerns regarding the impact that discharge from the Beausejour and other nearby rivers might be having on the near-shore coral communities, given the land-use activities observed in their catchment area. Accordingly, the management of the MBMPA, through the Grenada Fisheries Division within the Ministry of Agriculture, Lands, Forestry, Fisheries and the Environment, sought assistance from the Organization of American States *'ReefFix'* program to support research in this regard.

Consequently, this research assesses the impact that discharge coming from the Beausejour and other nearby rivers might be having on coral reefs in the MBMPA. This paper focuses on sediment inputs which can directly smother corals as well as bottom-up factors like nutrient inputs that can contribute to increases in macroalgae abundance on coral reefs in the MBMPA.

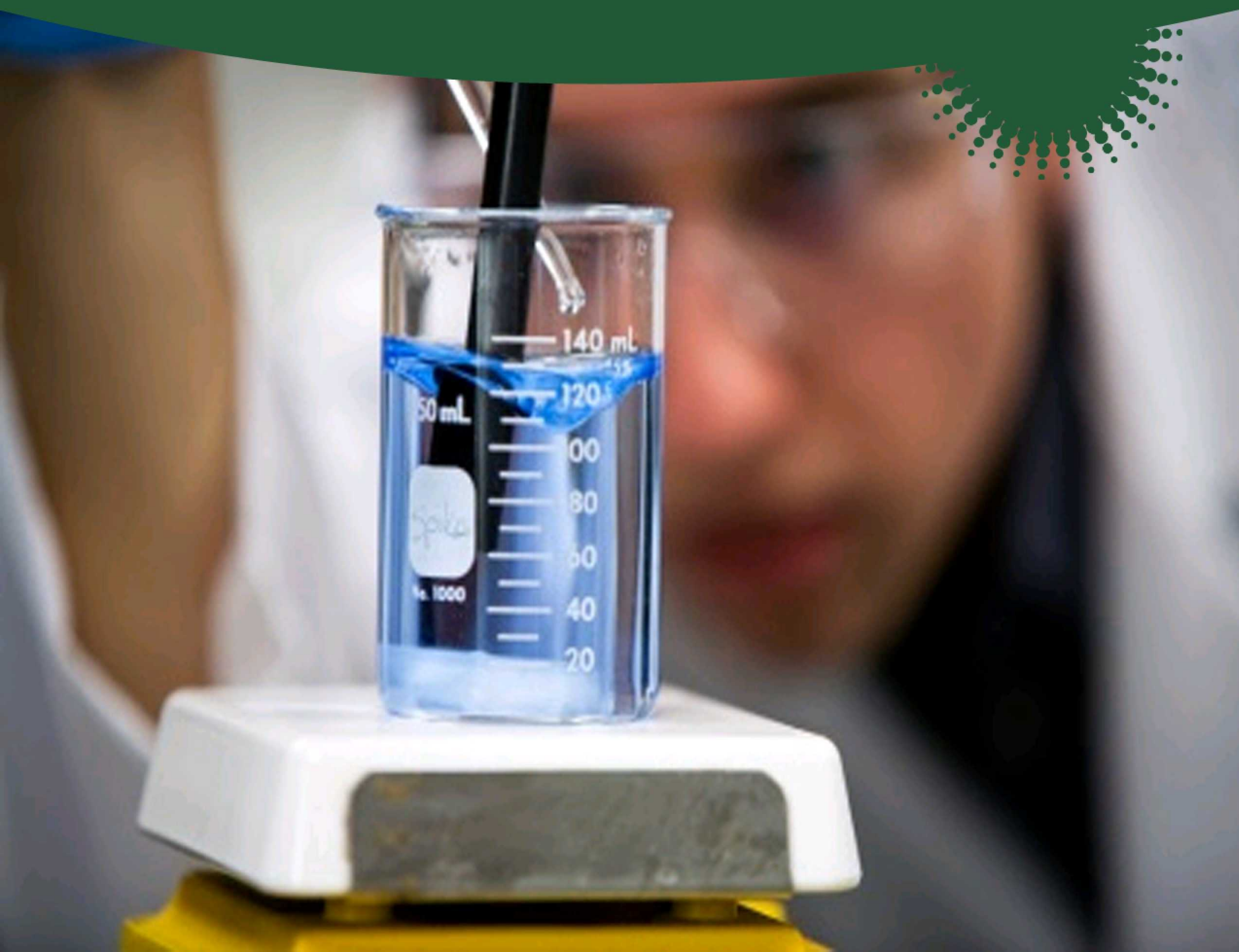
The specific objectives of this study are:

- To determine the levels of dissolved phosphate and ammonia (nutrients) in the Beausejour River as well as the near-shore coastal waters.
- To determine whether any eutrophication gradient exists in the river and in the near-shore coastal waters.
- To determine the levels of sedimentation on coral reefs in the MBMPA.
- To determine whether any sedimentation gradients associated with the discharge from the Beausejour River exist on coral reefs in the MBMPA.
- To determine the benthic composition of coral reefs in the Protected Area and the influence river discharge may have on its health.
- To identify possible sources of nutrients and sediment inputs into the Beausejour River.
- To make recommendations on ways to reduce or eliminate inputs of nutrients and sediments into the Beausejour River.

The results of this research will provide the MBMPA management and other agencies responsible for the protection of coral reefs in Grenada with information and directions to address a number of threats and stresses that affect coral reefs in the MBMPA. It will also provide relevant information upon which sound management decision and policies can be made to improve reef health in the MBMPA and Grenada.

4 | Method

Photography by IAS Laboratories



4.1 Study area

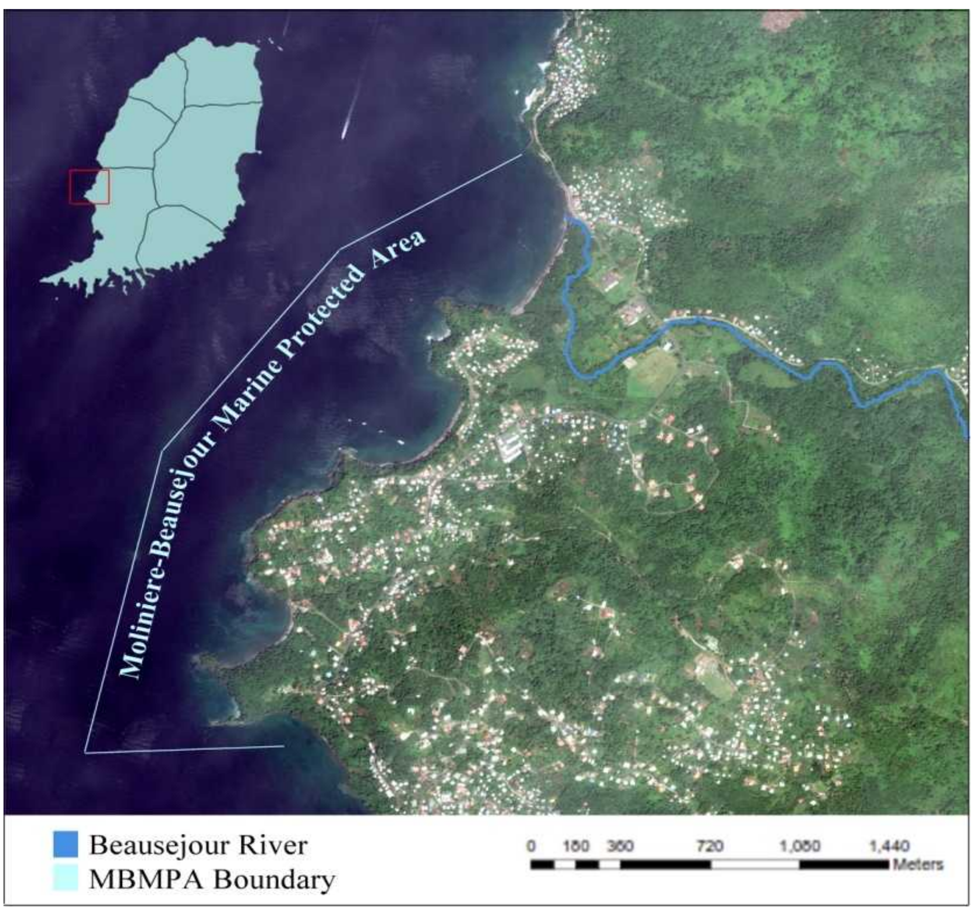
Beausejour River and catchment area

The Beausejour River is located on the west coast of Grenada (N 12° 05. 899, W 061° 45. 126), approximately 5 kilometers north of the capital, St. George's. Its catchment area covers approximately 1432 hectares and is characterized by steep hillsides and mountainous terrain which are used primarily for agricultural activities such as crop cultivation and livestock rearing. There is a considerable amount of human settlements, primarily domestic dwellings, within the lower portion of the catchment area, while the upper areas exhibit a much sparser distribution.

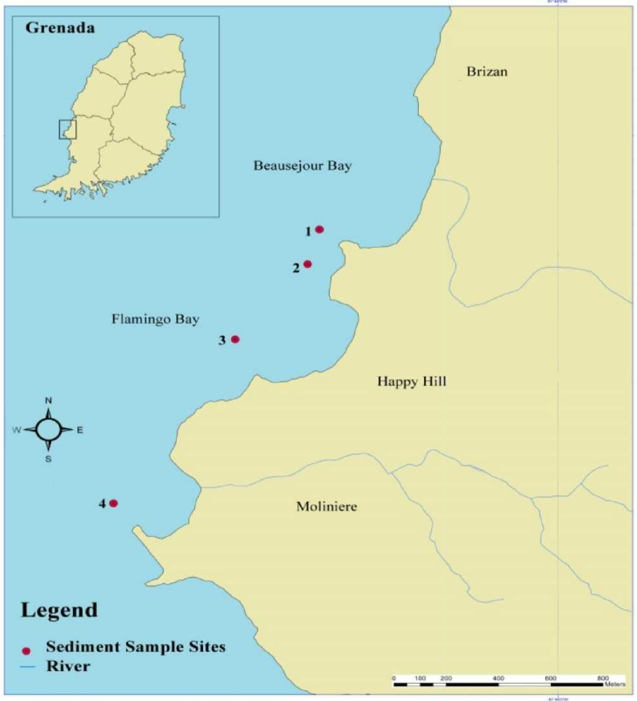
Although the Beausejour River and catchment area are the main features of this study, there are two smaller rivers in close proximity to the MBMPA. These are the Salle River which runs approximately 1.28 km to the north of the Beausejour River and the Dragon Bay River which runs approximately 1.6 km to the south.

Near-shore coastal area

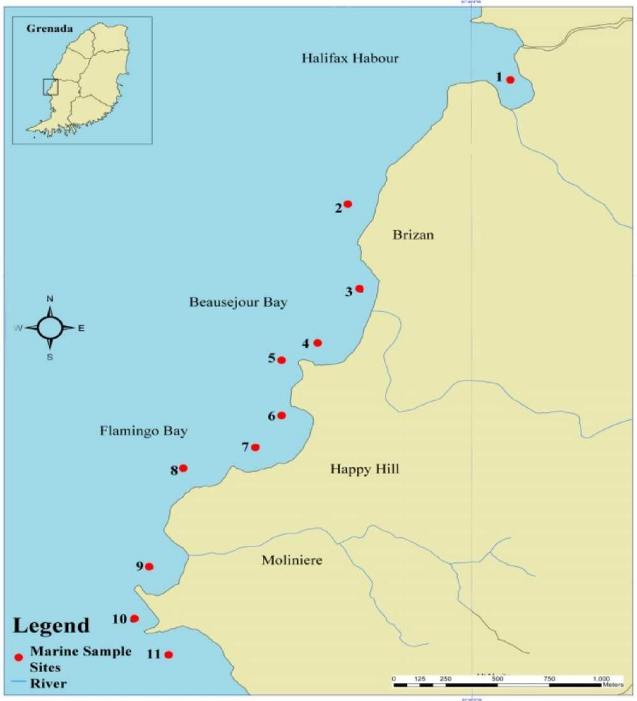
The Beausejour River discharges into the MBMPA on the leeward side of the island (Satellite image 1). It provides a well-defined point source of input into the MBMPA's near-shore coastal area which is comprised of a system of narrow spur and grove fringing coral reefs and areas of seagrass beds.



Satellite image 1. Study area showing Beausejour River, catchment area and the Moliniere-Beausejour Marine Protected Area



Map 1. Four sediment sample sites within the MBMPA.



Map 2. Eleven marine water sample sites.

4.2 Sedimentation

A total of 36 sediment traps 11 cm long x 5 cm in diameter were deployed at four coral reef sites within the MBMPA during January 2013 to assess sedimentation rates (Map 1). In order to identify and quantify any sedimentation gradients associated with the discharge from the Beausejour River on the adjacent coral reefs, sediment traps were placed at increasing distances away from the river mouth in a southward direction along the coast in the protected area. At each site steel rods were hammered firmly and securely into the substratum in a vertical position. Three sediment traps (1 set) made from PVC tubes were attached to the steel rod with tie straps (Image 1). The traps were attached to the rod so that the bases of the traps were 20 cm above the substratum and the rod did not protrude above the opening of the traps to create turbulence (English et al. 1997). At each reef site, a set of traps were deployed at three different depths 4.5-5.5 m, 9.2-10 m and 15.8-16.5 m for a period of 5 days (5-10 January 2013). The traps were sealed with plastic bags before removing them from the rods to prevent loss of material while bringing the samples to the surface. The whole sample, including the seawater contained in the traps was taken back to the laboratory for measurement. The seals of the traps were removed in the laboratory and the sediments filtered from the water contained in each trap (English et al. 1997). The filtered samples were dried for 24 hours in an oven at 80°C and the sediments weighed.

4.3 Marine Sampling

Near-shore marine water samples were collected at eleven locations along the west coast of Grenada between Grand Mal Bay and Halifax Harbor. These included three locations to the north of the Beausejour

River mouth and seven locations to the south (Map 2).

The samples were collected from 50 cm above the sea floor in pre-rinsed 3.5 L Niskin bottle (model 10 10 – 1.2) and transferred to clean 250 ml Nalgene (brown) bottles. At each location, two samples were collected, stored on ice and immediately transported to the St. George's University Marine Station (Grenada) for laboratory analysis. Sampling was done on three occasions (18, 22 December 2012 and 18 January 2013) after varying degrees of rainfall.

4.4 River Sampling

Freshwater samples were collected at three points along the course of the Beausejour River to assess the levels of dissolved nutrients and investigate whether any eutrophication gradients exists within the river.

The three sample points were selected based on human settlements and agricultural activities in the catchment area. The upper point (N 12° 05. 521, W 061° 42. 858) was the closest to the source of the river, which was essentially above all human settlements and above most major agricultural activities. The middle point (N 12° 06. 272, W 061° 44. 656) was located further down the course of the river, below a significant increase in human settlements and agricultural activities in the catchment area. The third sample point (N 12° 05. 899, W 061° 45. 126) was at the mouth of the river immediately before it discharges into the sea.

Freshwater samples were also collected from the mouths of the Salle and Dragon Bay rivers, which are in close proximity to the MBMPA along the west coast of Grenada for comparison. At each point, two samples were collected in clean 250 ml Nalgene (brown) bottles, stored on ice and immediately transported to the St. George's University Marine Station laboratory (Grenada) for analysis.

River sampling was done on two occasions, once after a period of heavy rainfall (19 December 2012) and another following a period of no rainfall (25 January 2013).

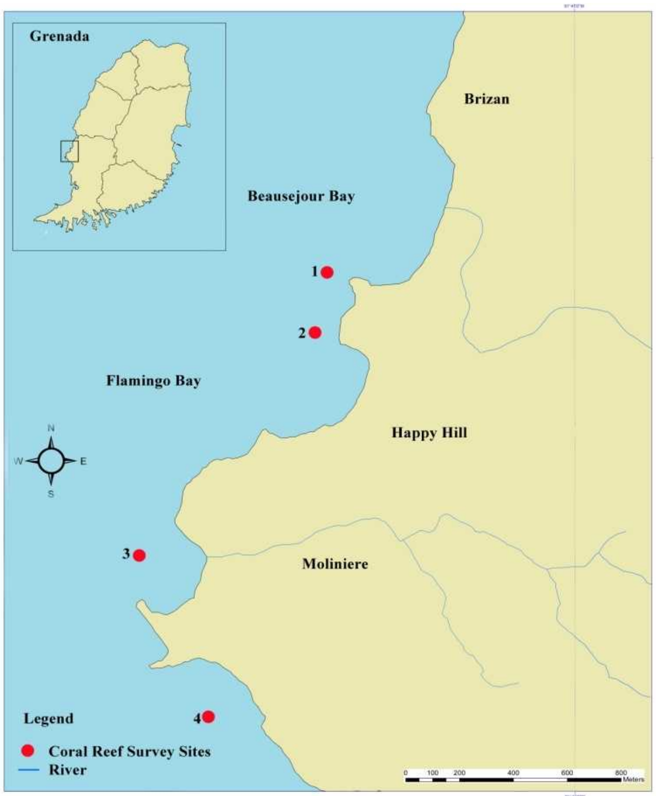
4.5 Nutrient Analyses

Both freshwater and marine water samples collected were analyzed according to methods described by Strickland and Parsons (1968) to determine phosphate concentrations, and Solórzano (1969) to determine ammonia concentrations.

4.6 Coral reef Sampling

Four coral reef sites within the MBMPA (Beausejour, Flamingo North, Dragon Bay and Grand Mal) were surveyed during December 2012 and February 2013 (Map 3).

At each site, a series of 3 x 10 m transects were established to determine the benthic percentage cover. Transects were placed 5 m apart along the reef contours parallel to the



Map 3. Four Coral Reef survey sites within the study area.

reef front at three survey depths 4.5-5.5 m, 9.2-10 m and 15.5-16.5 m. For each transect, the distance covered by each benthic component was measured in centimeters (cm) to determine the benthic percentage cover of the reef. Benthic percentage cover was calculated using benthic codes described by Perry et al. (2012)

4.7 Sources of nutrient and sediment Input

A number of visual surveys of the Beausejour River catchment area were conducted to identify possible sources of nutrient and sediment inputs into the river. Consultation workshops were also held with farmers and other users in the Beausejour catchment area to further identify possible sources of nutrient and sediment inputs. At these workshops, potential solutions for reducing and eliminating nutrient and sediment inputs from land runoff were explored and examined.

4.8 Data analysis

To determine whether any sedimentation gradients associated with the discharge from the Beausejour River exists, a Kruskal-Wallis Test was performed on sedimentation data to compare rates of sedimentation (mg cm^{-2} d^{-1}) between the different sites.

To test for differences between benthic components among the sites and within sites, one-way ANOVAs were performed on Arcsin log-transformed data. Tukey's post hoc test was used to further investigate significant differences among benthic components and sites. Statistical analyses were performed using Minitab version 16 statistical software package.

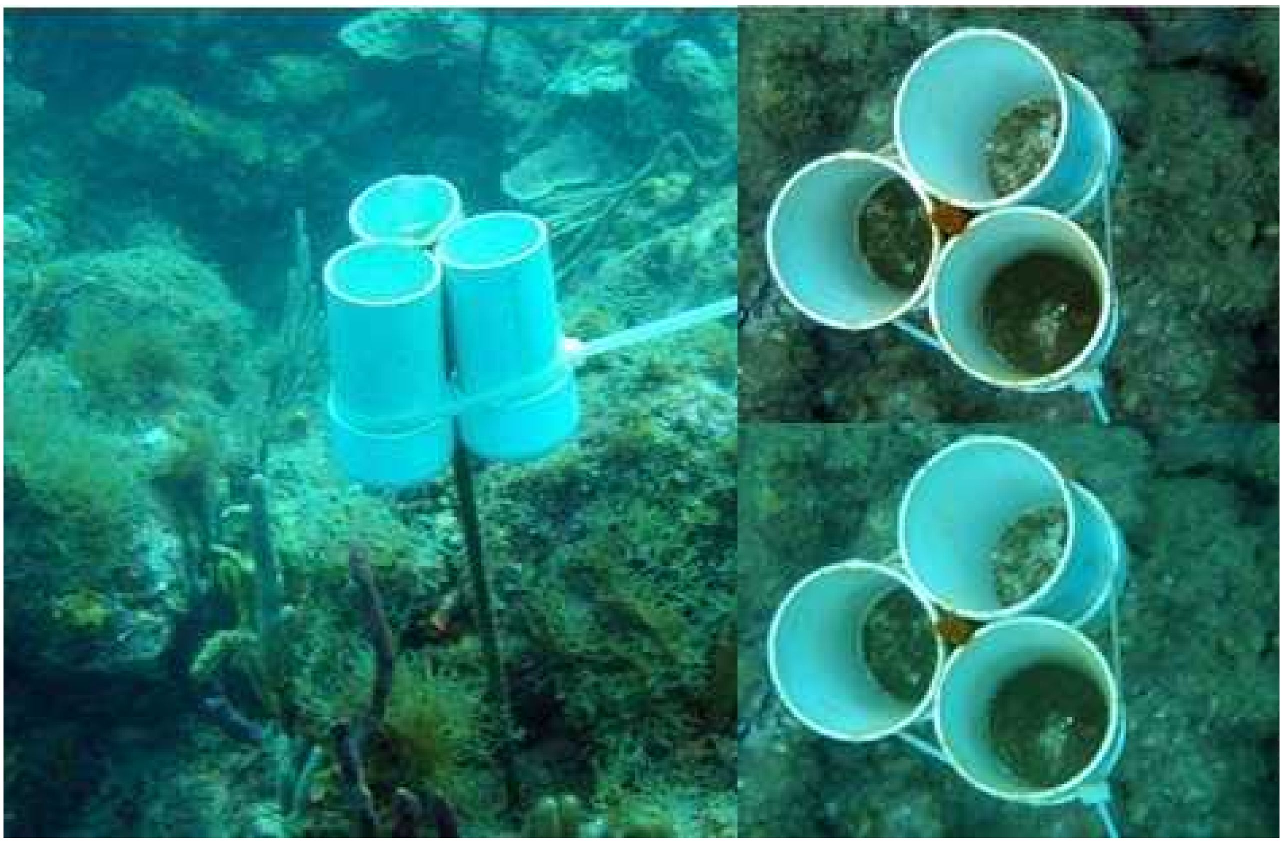


Image 1. Sediment trap sets deployed in the Moliniere-Beausejour Marine Protected Area (MBMPA)

5 | Results

Section of reef close to the mouth of
Dragon Bay River
Photography by Stephen Numrod

5.1 Sediment inputs

A sedimentation gradient associated with the Beausejour River mouth was observed with mean sedimentation rates decreasing with increasing distance from the river mouth (Chart 1). Mean rates of sedimentation ranged from 3.65 ± 2.11 ($mg/cm^2/d$ ± SD) at Beausejour Point which was closest to the river mouth, to 1.10 ± 0.25 ($mg/d/cm^2$ ± SD) at Dragon Bay which was furthest from the river mouth. A Kruskal-Wallis Test revealed that mean sedimentation rates varied significantly among the sites sampled (Kruskal-Wallis, df = 3, H = 8.64, *P* = <0.034), in which, Beausejour Point and Flamingo Bay North had significantly higher mean rates of sedimentation (3.65 ± 2.11, 3.23 ± 1.17 {$mg/cm^2/d$ ± SD} respectively) than Flamingo Bay and Dragon Bay (0.92 ± 0.31, 1.10 ± 0.25 {$mg/cm^2/d$ ± SD} respectively). Mean rates of sedimentation at all sites were lower than the threshold level of 10 mg 1^{-1} or 10 mg cm^{-2} d^{-1} highlighted by Rogers (1990) and Fabricius (2005).

5.2 Nutrients in the Beausejour River

A eutrophication gradient was observed in the Beausejour River with phosphate and ammonia concentrations increasing with increasing distance down the course of the river (Chart 2). At all the points sampled, higher phosphate concentrations were observed following a period of rainfall (upper: 169 ± 31.1 µg/L, middle: 227 ± 1.5 µg/L, mouth: 286 ± 20 µg/L) as compared to after a period of no rainfall (upper: 58.5 ± 48 µg/L, middle: 166 ± 0 µg/L, mouth: 200 ± 44 µg/L). With the exception of the upper sample point, ammonia concentrations were higher after rainfall as compared to after no rainfall (Chart 2.b). Phosphate concentrations were higher than ammonia concentrations at all sample points (Chart 2.a). All phosphate and ammonia measured from the Beausejour River exceeded the maximum allowed levels recommended by Caribbean Environmental Health Institute (CEHI).

5.3 Nutrient inputs from other rivers

Phosphate and ammonia concentrations at the mouth of the Beausejour River were lower than those at the mouths of two other nearby rivers; the Dragon Bay River and the Salle River (Table 1). Nonetheless, the phosphate and ammonia concentrations in all three rivers exceeded the maximum allowed limits recommended by CEHI for coastal waters. With the exception of the Salle river mouth, all phosphate concentrations were higher after rainfall. However, mean phosphate concentrations at the mouth of the Salle River were relatively similar after rainfall and after no rainfall. All ammonia concentrations were higher after rainfall except at the Dragon bay river mouth.

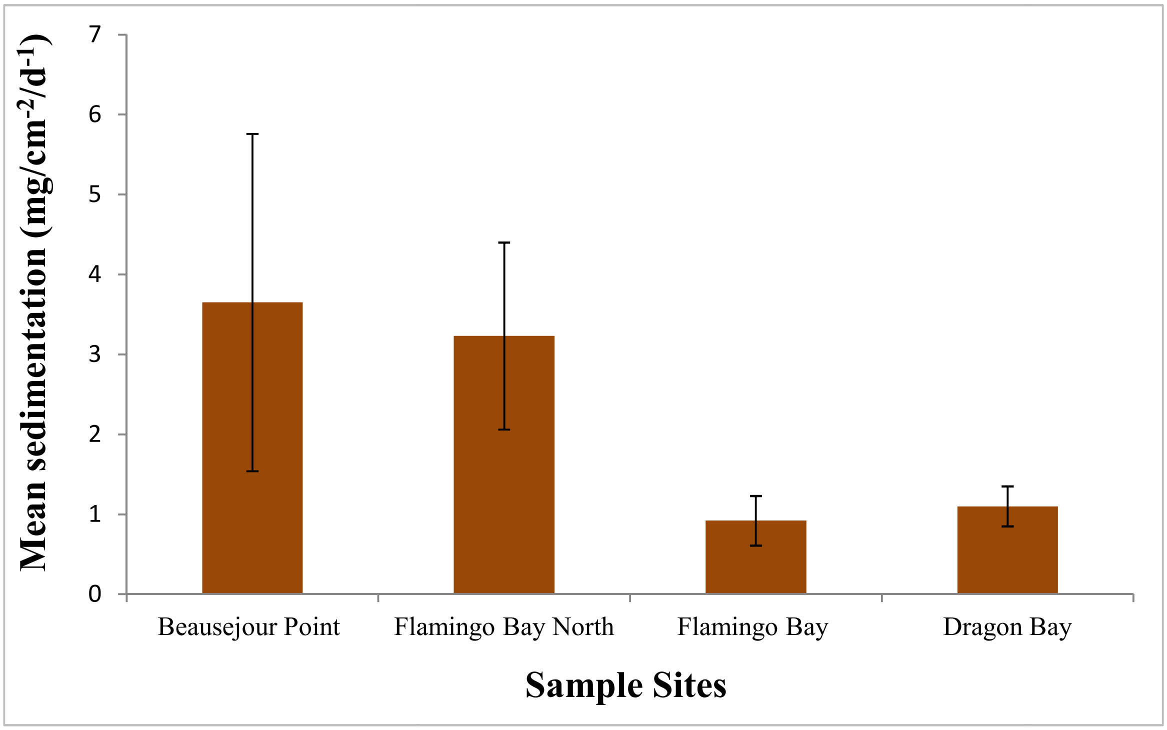


Chart 1. Mean sedimentation rates (mg/d/cm^2 ± SD) at four coral reef sites within the Moliniere Beausejour Marine Protected Area. The four sites were at increasing distances from the mouth of the Beausejour River with Beausejour point being the closest site and Dragon Bay the furthest site. At each site 3 traps (1 set) were deployed at three different depths 4.5-5.5 m, 9.2-10 m and 15.8-16.5 m for a period of five days (5-10 January 2013). The sediment traps were made from PVC tubes 11 cm long x 5 cm in diameter. Error bars are standard deviation (SD) of the mean.

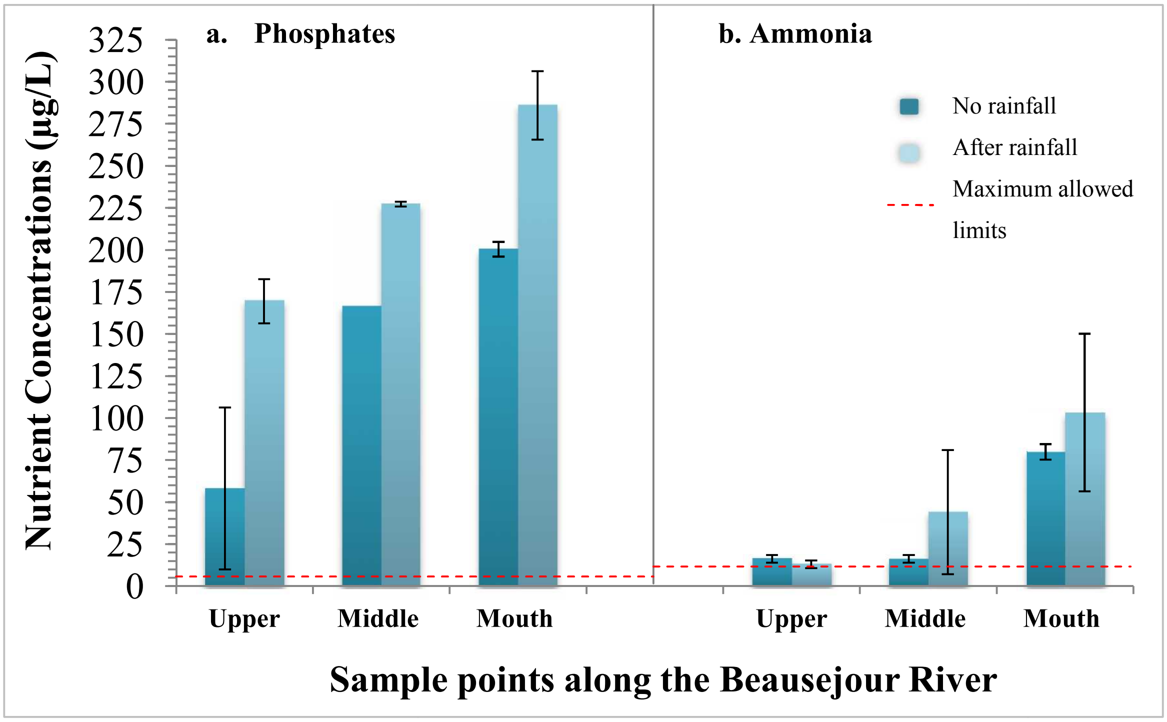


Chart 2. Nutrient concentrations at three sample points along the Beausejour River following a period of no rainfall and after rainfall. (a) Phosphate concentrations (µg/L); Red dash represents a maximum allowed limit of 5 µg/L. (b) Ammonia concentrations (µg/L); Red dash represents a maximum allowed limit of 10 µg/L. Error bars indicate standard deviation of the mean.

Table 1. (a) Phosphate and (b) Ammonia concentrations (µg/L) for sample points at the mouth of three rivers that discharge in close proximity to the Moliniere-Beausejour Marine Protected Area (MBMPA) following periods of heavy rainfall and no rainfall. Values are means ± SD.

a. Phosphate Concentrations

	After rainfall (December 19, 2012)	**No rainfall (January 25, 2013)**
Sample Site	Mean Concentration (µg/L)	Mean Concentration (µg/L)
Salle River mouth	490.1 ± 440.3	534.4 ± 100.6
Beausejour River mouth	286.0 ± 20.4	200.4 ± 4.4
Dragon Bay River mouth	1242.7 ± 35.0	525.2 ± 1.5.0

b. Ammonia Concentrations

	After rainfall (December 19, 2012)	**No rainfall (January 25, 2013)**
Sample Site	Mean Concentration (µg/L)	Mean Concentration (µg/L)
Salle River mouth	8130.6 ± 6128.6	6590.0 ± 32.3
Beausejour River mouth	103.3 ± 46.9	79.9 ± 4.6
Dragon Bay River mouth	263.1 ± 145.3	417.5 ± 196.0

5.4 Phosphate concentrations in coastal waters

On each sampling day, a number (cluster) of marine sample points in relatively close proximity to the mouths of the three rivers (Salle, Beausejour and Dragon Bay) had relatively high phosphate concentrations compared to other sample points. These clusters suggest a eutrophication gradient associated with a plume type of discharge from the various river mouths (Chart 3) Phosphate concentrations at the sample points varied with varying rainfall levels on the three sampling days. Many of the sample points had phosphate concentrations that exceeded the maximum allowed limits recommended by CEHI for marine and coastal waters.

5.5 Ammonia concentrations in coastal waters

On sample days one and two many of the samples contained ammonia concentrations that were below the detectable levels. On the third day, samples showed a similar pattern to the phosphates, with elevated levels found in the samples in closer proximity to the river mouths (Chart 4).

5.6 Benthic Composition

The four reefs surveyed were similar in benthic composition (ANOVA: df = 3, F = 0.03, P = 0.99). Algae comprised the largest component of substrate on all sites with a mean percentage cover ranging from 57% (± 20%) at Flamingo Bay North to 48% (± 12%) at Dragon Bay (Chart 5). Benthic

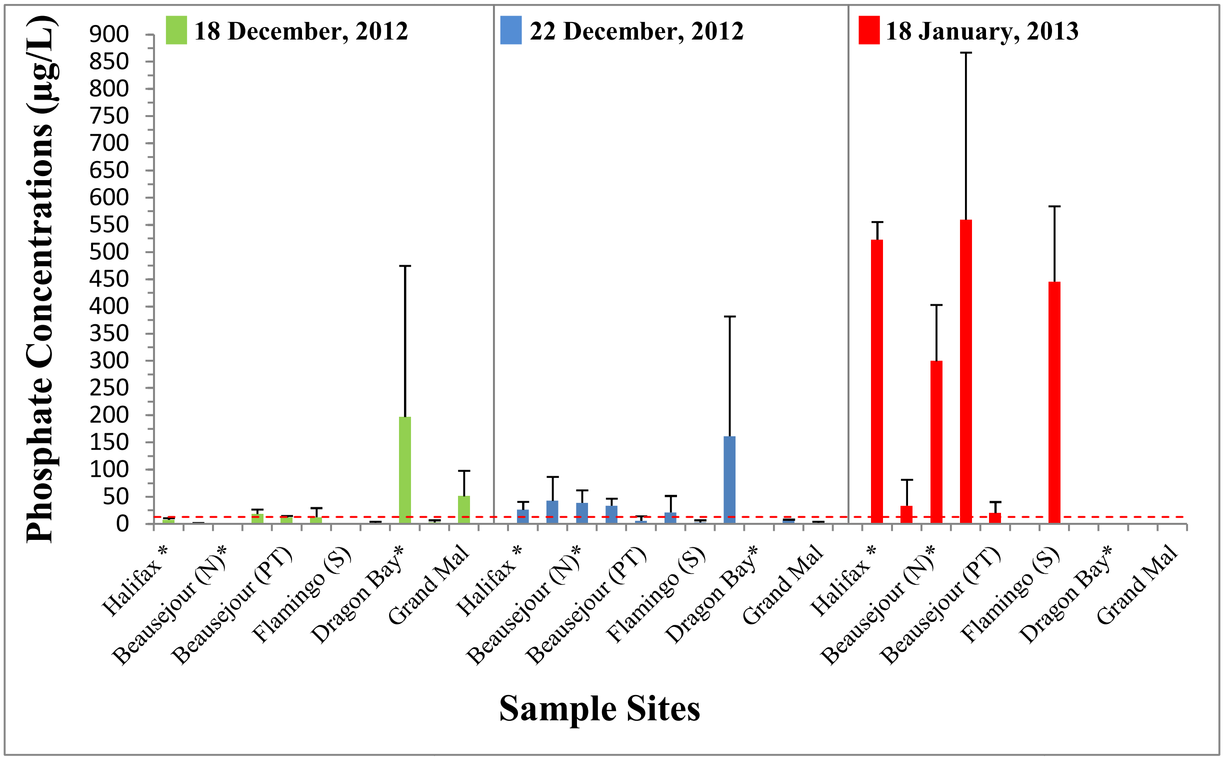


Chart 3. Phosphate concentrations (µg/L) at eleven marine sample sites within the Moliniere-Beausejour Marine Protected Area (MBMPA) for three different sampling days. (*) indicates points of direct river discharge (river mouths). Error bars indicate standard deviation of the mean.

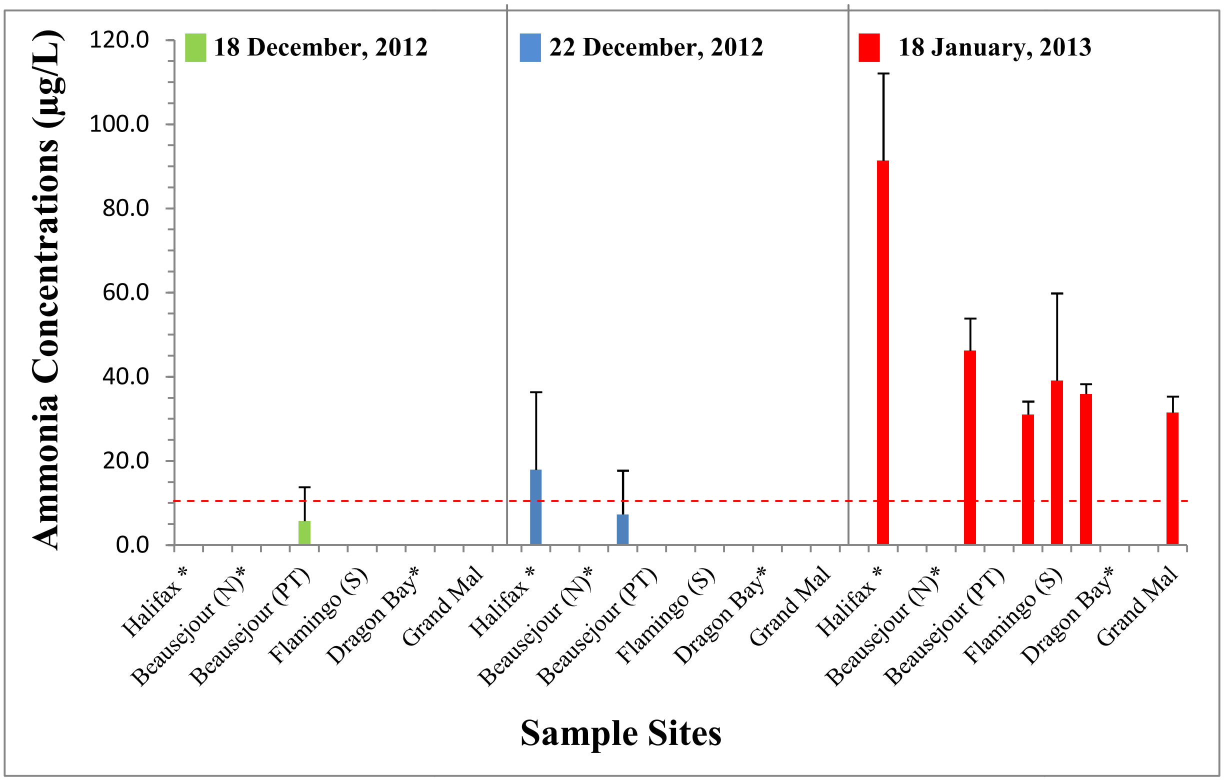


Chart 4. Ammonia concentrations (µg/L) at eleven marine sample sites within the Moliniere-Beausejour Marine Protected Area (MBMPA) for three different sampling days. (*) indicates points of direct river discharge (river mouths). Error bars indicate standard deviation of the mean.

components within the reef sites varied significantly (ANOVA: df = 6, F = 44.72, P = < 0.001). Tukey post hoc test revealed that algae percentage cover was significantly higher than all other benthic components on all sites. Hard coral comprised the third most common component of the substrate at all sites ranging from 25% (± 17%) at Flamingo Bay North to 9% (± 7%) at Grand Mal.

5.7 Sources of nutrient and sediment inputs

The sources of nutrient and sediment inputs into the Beausejour River were mainly associated with inappropriate agricultural and land use practices, as well as inadequate wastewater disposal and sanitation facilities.

5.7.1 Clear cutting and over-clearing of lands

Large portions of land on steep hillsides and in very close proximity to the river banks were clear-cut for cultivation of crops in the catchment area In addition to this, farmers tend to clear considerably more land than is required for cultivation of their crops. These large portions of exposed soils are then prone to erosion and usually result in runoff containing increased levels of sedimentation and nutrients which then enter the river and marine environment.

5.7.2 Cultivation of crops too close to the river

Farmers were observed cultivating vegetable crops in very close proximity to the river in order to access the river water to irrigate these crops (Image 2). In many cases, these areas close to the river were clear-cut and tilled with considerable amounts of fertilizer applied to the area through the broadcasting method. Following periods of heavy rainfall, the exposed soils with the fertilizer are eroded directly into the river which eventually discharges into the coastal marine environment. This contributes to increased levels of sedimentation and nutrients entering the river via runoff from the land.

5.7.3 Improper use of fertilizers

Broadcasting of fertilizers onto fields by hand is the most common method of fertilizer application among farmers in the catchment area. Large quantities of un-dissolved fertilizer eventually become washed into the river through soil erosion during and after rainfall. Additionally, soil testing is rarely conducted by farmers in the catchment area due to the associated cost. Consequently, fertilizers are usually not applied in correct proportions to suit the soil type and crop requirements. These practices result in over-use and misuse of fertilizers in the catchment area.

5.7.4 Inappropriate livestock farming practices

Within the Beausejour river catchment, a number of small livestock farms, primarily pig farms, were observed in relatively close proximity to the river. These farms possess inadequate sanitation facilities and as such, regular cleaning (washing) of these livestock pens result in wastewater containing feces and excess feed entering the river via small drains. The unused feed and feces can then

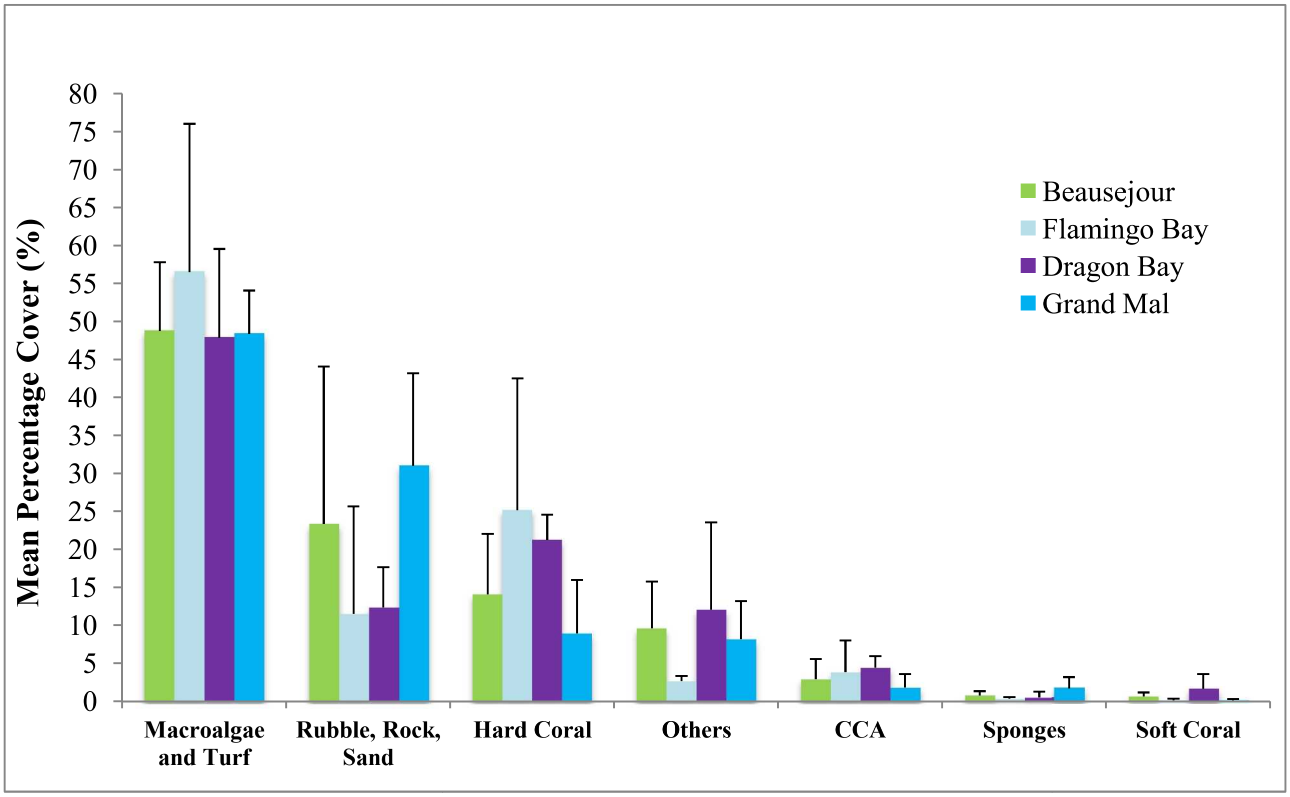


Chart 5. Mean percentage benthic cover for four reefs within the Moliniere-Beausejour Marine Protected Area (MBMPA) surveyed during December 2012 and February 2013. Error bars indicate standard deviation of the mean.

be considered contributors to increased levels of nutrients entering the Beausejour River.

Additionally, a number of ruminant livestock such as cattle, sheep and goats were observed tethered very close to the river bank to allow grazing and easy access to the rivers' fresh water. These animals tend to over-graze the vegetation and release considerable quantities of feces in these areas, which are later washed into the river during rainfall. This scenario also contributes to excess nutrients and sedimentation entering the river.

5.7.5 Indiscriminate use of detergents in and close to rivers

A number of residents were observed on several occasions washing laundry in the river and washing motor vehicles near the river with soaps and detergents. Many of the soaps and detergents being used by these individuals are high in phosphates (Image 3). This will contribute to the excess nutrients entering the river.

5.7.6 Domestic dwelling with inadequate grey-water facilities

Some domestic settlements in relatively close proximity to the river had small drains discharging considerable amounts of grey-water which would eventually leach into the river.

Image 2. Farmers in the Beausejour River catchment area tend to plant crops close to the rivers' edge to easily access fresh water for irrigation. This makes it easy for nutrients to be leached into the river with continued irrigation, and for nutrients and sediments to be washed into the river during rainfall.

Photo © Robert Balza

Image 3. Many residents in the Beausejour Rivers' catchment area wash their laundry directly in the rivers' water, using high phosphate soaps and detergents such as this 'Impact' detergent which was discarded in the area after use.

6 Discussion

Consultation workshop with farmers,
Black Bay, St. John's, Grenada.
Photography by Stephen Numrod

6.1 Sedimentation

The sedimentation gradient observed in this study indicates that riverine discharge from the Beausejour River is a major source of sediment loading on some coral reefs in the MBMPA. The relationship in which sediment loads decreased with increasing distance away from the mouth of the Beausejour River is similar to patterns observed in other studies (Fabricius 2005; Van Woesik et al. 1999).

Terrestrial (land) runoff associated with soil erosion during rainfall appears to be largely responsible for the sediment loading in the Beausejour River. In addition to smothering and weakening of corals, sediment accumulation can strongly suppress herbivory on coral reefs which could reinforce phase-shifts to an algal dominated state (Bellwood and Fulton 2008; Rasher et al. 2012). Sediment accumulation can also suppress coral growth and survivorship (Fabricius 2005). It should be noted that although the sedimentation rates in this study were below the lethal level highlighted by Rogers (1990) and Fabricius (2005), chronic sedimentation can eventually result in coral mortality.

6.2 Eutrophication gradient in the Beausejour River

Our results showed that a eutrophication gradient exists in the Beausejour River whereby phosphate and ammonia concentrations increase with increasing distance down the course of the river. This trend was an expected result because agricultural activities and domestic settlements also increased with increasing distance down the course of the river. The results suggests that agriculture and the domestic settlements within the catchment area are major sources of nutrient loading in the Beausejour River, with a loading effect which culminates at the rivers' mouth.

The intense use of fertilizers by farmers in the catchment area as well as runoff from small livestock farms in close proximity to the river also appear to contribute significantly to the nutrient loading observed in the Beausejour River. Agriculture and urban settlements have been identified as sources of inputs of nutrients in other studies (Unknown 2009).

6.3 The relationship between rainfall and nutrients in the Beausejour River

Increases in phosphate and ammonia concentrations recorded after rainfall suggests that the sources of nutrients entering the Beausejour River are largely associated with soil erosion and land runoff. This is usually referred to as diffuse sources of input, which are in contrast to point sources of input, such as drains and outfalls. Point sources may have a consistent volume and flows irrespective of rainfall. Thus concentrations of nutrients in such cases may decrease after periods of rainfall rather than increase due to the dilution factor.

6.4 Higher phosphate concentration than ammonia in the Beausejour River

The results showed that phosphate concentrations were much higher than ammonia for all the samples in the Beausejour River. This can be partly explained by the stability of the nutrients measured. Phosphate (PO_4) is very stable and as such will persist in water for very long periods. Ammonia (NH_4), on the other hand, is a relatively unstable form of nitrogen and is quickly oxidized and converted into nitrite and then into nitrate (Bothe and Ferguson et al. 2006). Hence situations may occur in water bodies where ammonia concentrations are low while nitrate concentrations are high. As such, ammonia is generally a good indicator of recent contamination events. It would have been ideal to measure both ammonia and nitrates for this study; however we were unable to measure nitrates due to limitations.

The type of fertilizers used by farmers in the catchment area can also partly explain the higher phosphate to ammonia concentrations recorded at all sample sites. The fertilizer most frequently used is a combination of Nitrogen, Potassium and Phosphorous (NPK) with a component ratio of 12:8:24 respectively. This fertilizer, having a higher ratio of phosphate than ammonia will result in greater inputs of phosphate than ammonia into the river.

6.5 High nutrient levels upstream in the Beausejour River

High concentrations of phosphate were recorded in the upper portion of the Beausejour River. This was an unexpected result because the upper sample point should have been located above all human settlements and agricultural activities. Moreover, it was expected that the upper sample points would have similar nutrient concentrations both before and after rainfall, since it was believed that no major sources of input other than the natural sources of nutrients existed. However, upon further investigation it was discovered that there were some agricultural activities above the upper sample point, although there are no domestic settlements within that area. This can partly explain the relatively high phosphate readings recorded in the upper portion of the river.

6.6 Nutrients in other river mouths

Although the Beausejour River had very high nutrient concentrations, it was still the lowest of the three river mouths sampled. This may be as a result of the activities that occur in the respective river catchments and the differences in the sources of nutrient inputs into each of the three rivers. For instance, the Salle River flows directly through Grenada’s lone landfill, seeping through and filtering its contents. This undoubtedly will have a significant influence on the levels of nutrients being discharged from the Salle River. Hence it is not surprising that the Salle River had considerably higher concentrations of nutrients than the other two rivers.

While very little is known about the sources of nutrient inputs into the Dragon Bay River at this point, it is expected that the activities occurring within the catchment will certainly influence its nutrient levels. Further investigation is needed to ascertain the sources of nutrient inputs into the Dragon Bay River.

6.7 Nutrient levels before and after rainfall in the other rivers

The decrease in ammonia concentration recorded after rainfall in the Dragon Bay River may be explained by the source of input combined with the dilution factor associated with rainfall. This decrease is suggestive of a point source of input such as a drain or outfall which may have a consistent flow volume of input. During the dry period, the volume of water in the river should decrease and the concentration of ammonia is expected to increase. However, after periods of rainfall, the volume of water in the river should increase and the concentration of ammonia is expected to decrease. This is in contrast to diffused sources of input such as runoff from erosion which most likely will increase with increasing rainfall and runoff.

The considerably large variation (standard deviation) in mean phosphate concentration recorded at the mouth of the Salle River after rainfall could be due to the small number of replicates. This large variation could be reduced by increasing the number of replicates per sample in future studies.

6.8 Nutrients in marine waters and its impacts on coral reefs

Dissolved phosphate and ammonia concentrations recorded in the mouth of the three rivers sampled, as well as some clusters of marine samples near the river mouths were very high. This data implies that riverine discharge from the Beausejour and the other two rivers are major sources of nutrient inputs into the near-shore coastal waters.

The nutrients discharged from these rivers can play a critical role in stimulating algae growth in marine and aquatic ecosystems. Phosphate in particular is one of the most limiting nutrients for algae growth in aquatic ecosystems (Alongi 1998; Correll 1999). Moreover, having such high concentrations of these nutrients in the water column will undoubtedly help stimulate rapid growth and proliferation of macroalgae. Therefore, based on the data presented in this study, it is reasonable to conclude that excess nutrients (eutrophication) in the water column is a major factor contributing to the high percentage cover of macroalgae recorded on the coral reefs surveyed in the MBMPA (Image 4a & 4b).

It will be more difficult for the current herbivore population on the reefs in the MBMPA to effectively keep algae in a grazed state in the presence of such high concentrations of nutrients. Smith et al. (2010) in a recent study pointed out that grazing by herbivores reduces algae cover on degraded reefs, but is most effective in the absence stressors such as nutrient pollution.

The authors of this paper are not debating which factor; “bottom up” or “top down” is more important in driving (causing) the high abundance of macroalgae on these reefs, but rather acknowledges that both factors are contributing significantly to the high percentage cover of macroalgae recorded on the reef in the MBMPA. Therefore, both factors; reduced herbivory and eutrophication will have to be addressed in order to effectively initiate a shift in benthic composition on those reefs from algal dominated to coral dominated.

Urgent action relating to land use management in the catchment area is needed to address these issues which are negatively impacting the water quality. Such actions will compliment some management actions already initiated by the MBMPA Authority to increase herbivory on reefs in the MBMPA. Nutrient pollution is a priority challenge for the Beausejour River and the MBMPA.

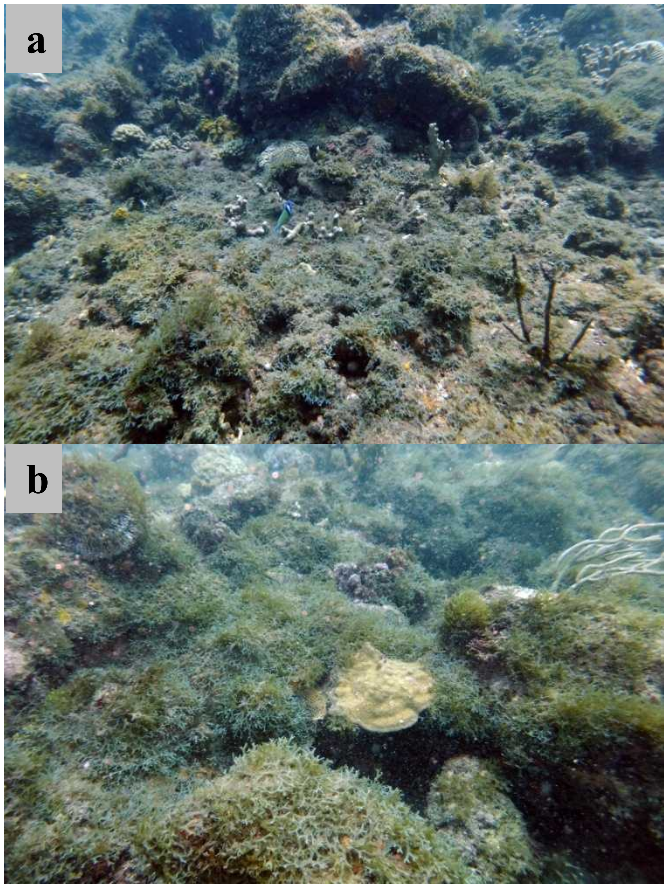


Image 4. Many reefs in the Moliniere-Beausejour Marine Protected Area are experiencing a proliferation in macroalgae growth.

These macroalge compete with corals for space, block-out sunlight and smother corals.

7 | Recommendations

Section of reef within the Moliniere-Beausejour Marine Protected Area
Photography by Coddinton Jeffrey

Multidisciplinary stakeholder group recommendations

The inputs of nutrient and sediments into the Beausejour River can be substantially reduced through the implementation of a combination of education and enforcement of best agricultural practices and improved sanitation facilities.

To be effective, the recommendations will have to be practical in the local context, affordable and socially acceptable. Successful implementation of these recommendations will require a substantial educational component with some incentives.

7.1 Crop cultivation management

(Awareness program, policy, incentives)

- Reduce the use of mineral fertilizers in the catchment area through awareness programs
- Conduct soil testing analysis to determine appropriate fertilizer before application
- Ensure appropriate application of pesticides through awareness programs

7.1.1 Adopt erosion-minimizing cultivation practices

- Create vegetative buffer strips between the river and cultivation plots to filter runoff
- Preserve and restore riparian vegetation to help filter particles from erosion
- Avoid clear-cutting and over-clearing of lands, particularly on steep hillsides
- Avoid farming on steep hillsides as much as possible
- Use contours in crop cultivation on hillsides to reduce soil erosion
- Practice crop integration particularly on hillsides to help reduce soil erosion
- Encourage reforestation wherever possible within the catchment area

Avoid over-clearing of lands

Specific example:
Avoid extensive use of cutlass

Use “weed eaters/whackers” instead of cutlasses to clear and maintain perimeter and access areas to cultivated plots. Cutlasses tend to remove all the vegetation leaving the top-soil exposed and prone to erosion. “Weed eaters/wackers” on the other hand will help to maintain a short layer of grass/vegetation which will hold the top-soil together, substantially reducing sediment and nutrient loading via erosion and runoff.

Cost recovery mechanism options:

Grant funding, small revolving loan scheme for farmers to purchase “weed eaters/wackers”.

7.2 Livestock waste management

Options to improve infrastructure and sanitation facilities on livestock farms

- Install biogas digesters to manage waste and wastewater from livestock farms

- Install septic tanks and soak-away systems on livestock farms to manage wastewater
- Redirect animal effluent into settling ponds for natural filtration by vegetation
- Relocate livestock farms further away from the river
- Avoid tethering of animals close to the river (awareness program, policy, incentives)
- Control grazing intensity of animals (awareness program, policy, incentives)

7.3 Domestic wastewater and grey-water management

- Install separate smaller soak-away systems to manage grey-water coming from domestic settlements close to the river

7.4 Stewardship program

Create a stewardship program to build and foster deeper relations and communication among farmers, government agencies and community members. This program will help to build capacity to empower stakeholders and community members to take the lead in protecting their environment by being environmentally responsible in their daily lives.

7.4.1 Stewardship Program: Education and outreach program

- Implementation of continuous education and outreach programs for farmers and the wider community on the impacts of nutrient and sediment pollution on coral reefs, best agriculture practices and the importance of coral reefs
- Create a demonstration farm/plot illustrating best agricultural practices
- Training for advisors and agriculture Extension Officers

7.4.2 Stewardship Program: Incentives Program for farmers

- Create incentive programs that accredit, award and reward farmers for implementing good agricultural practices on their farms. Such programs should include benefits such as discounts, tax breaks and concessions among others for compliant farmers.
- Attach best practice conditions for farmers seeking to purchase government subsidize fertilizer

7.5 Introduce phosphate-free detergents

(Awareness program, policy, incentives)

The Grenadian government should move towards reducing the use of detergents containing phosphate through a phasing-out approach and introduce phosphate-free detergents.

7.6 Implementation of a land use policy

There is an urgent need for the creation and implementation of a land use policy for Grenada which should include best agriculture practices and agri-environmental measures.

7.7 Integrated coastal zone management

(Awareness program, policy, incentives)

Environmental agencies and government ministries need to work collaboratively to ensure environmentally sound and sustainable practices are carried out across the various sectors. An Integrated Coastal Zone Management (ICZM) approach will address a number of issues that hinders the effective management of marine and terrestrial ecosystems which are inextricably linked on islands like Grenada. Gustavson et al. (2000) emphasized the need for ICZM and has outlined approaches and potential benefits for ICZM in some Caribbean islands.

7.8 Remove the landfill at Perseverance

Create a 5 to 7 year plan of action to reduce the inputs into the Perseverance landfill by eventually moving towards a complete national recycling program.

7.9 Conduct a similar study for Dragon Bay River and other rivers

A similar study should be conducted in other rivers in close proximity to the MBMPA, namely the Dragon Bay and Salle Rivers.

Table 2. Summary table of Multidisciplinary stakeholder group recommendations and cost recovery mechanism options for facilitating each.

Interventions	Cost recovery mechanism options
Installation of Biogas chambers	Grant funding, small revolving loan scheme, surcharge on water bills within the watershed area, surcharge on electricity bills within the watershed area
Installation of septic tanks and soak away systems	
Installation of settling ponds	
Education and awareness programs	Grant funding
Removal of landfill and introduction of national recycling program	Environmental levy

Appendix

Table 3. Multidisciplinary stakeholder consultation workshops and activities held with various organizations throughout Grenada. These activities were geared towards sharing the results of the project with the aim of collectively formulating recommendations and cost effective options for the implementation of these recommendations.

Date	Stakeholders	Location	Presenters
18 March 2013	North East Farmers Organization	Willis Community, New Hampshire, St. Georges	Stephen Nimrod
11 April 2013	Farmers Organization	Black Bay Community Centre, Black Bay, St. John	Stephen Nimrod
6 May 2013	North East Farmers organization	Willis Community, New Hampshire, St. Georges	Stephen Nimrod
30 May 2013	North East Farmers Organization	Glass bottom Boat tour in the Moliniere-Beausejour Marine Protected Area	Stephen Nimrod
17 June 2013	North West Development Authority Inc.	Happy Hill Secondary School, Happy Hill, St. Georges	Stephen Nimrod
Scheduled for: **26 July 2013**	Grenada Sustainable Development Council	Grenada Public Workers Union Building, St. Georges	Stephen Nimrod

Consultation workshop with the North West Development Authority Inc.

Photo © Stephen Nimrod

Consultation workshop with the Black Bay Farmers Organization

Photo © Stephen Nimrod

Glass-bottom boat tour of the Moliniere-Beausjour Marine Protected Area with the North East Farmers Organization

Photo © Stephen Nimrod

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