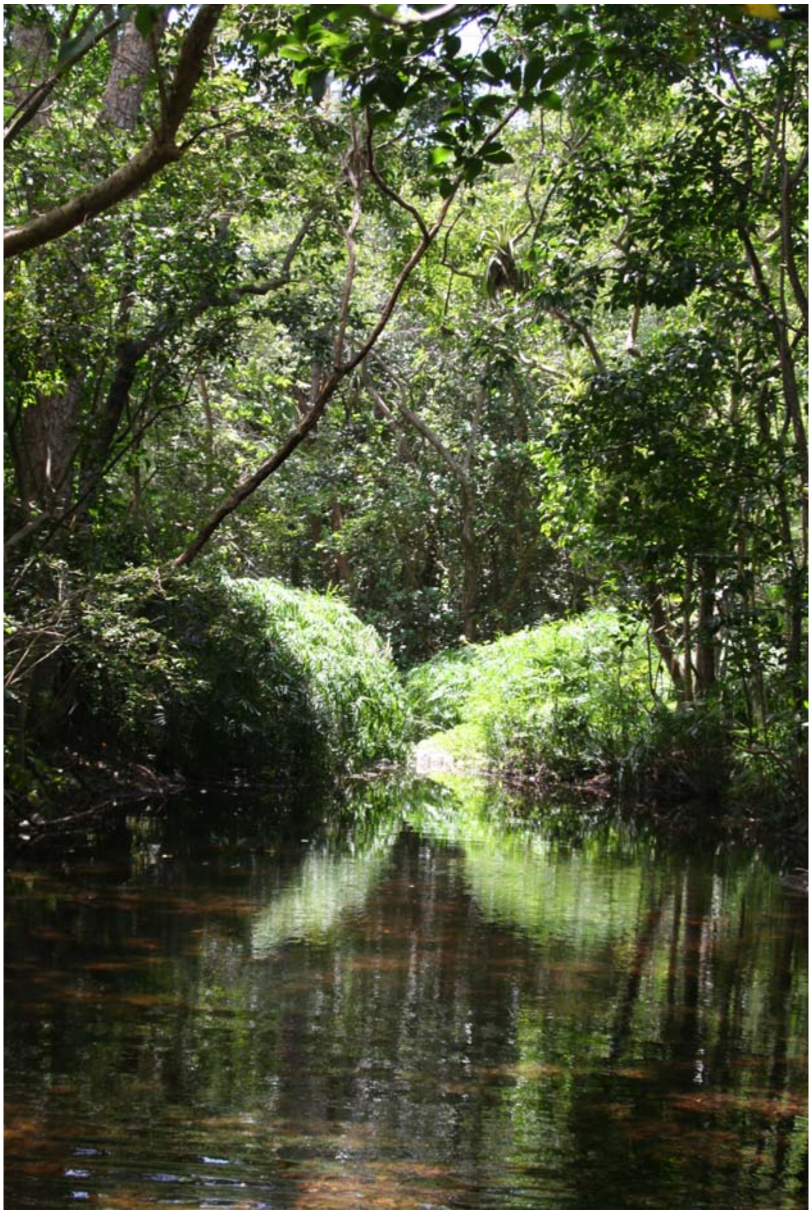
DIVERSITY OF FRESHWATER FISH AND CRUSTACEANS OF ST. THOMAS WATERSHEDS AND ITS RELATIONSHIP TO WATER QUALITY AS AFFECTED BY RESIDENTIAL AND COMMERCIAL DEVELOPMENT

WRRI Project 2006VI73B



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DISCLAIMER

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ABSTRACT

In the US Virgin Islands there has been considerable effort in surveying and mapping watersheds and riparian corridors. However, there has been little previous effort to document the freshwater systems, namely, the stormwater drainage guts. These guts form a vital connection between terrestrial habitats and upland activities and the downstream marine environment—yet research on the problems of non-point source pollution has largely overlooked the watershed habitat through which these pollutants are transported. Upland activities affect the levels of contaminants that flow through these habitats. We conducted a study to assess the impacts of levels of watershed development on the diversity of freshwater fauna. Three guts were selected that varied in development impact: Neltjeberg (low impact), Dorothea (moderate impact), and Turpentine Run (high impact). Freshwater habitats in a highly developed watershed contained more non-native fish species (guppies and tilapia) compared to those with low to moderate levels of development. The least impacted systems had higher native faunal diversity; Neltjeberg had 7 species of native shrimp and fish, compared to 5 in Dorothea and 4 in Turpentine Run. Total Phosphorous levels were highest in the most developed watershed (1.3-1.5, vs. 0.8-1.2 mg/L), and both Total Phosphorous and Total Kjeldahl Nitrogen were elevated downstream of a residential sewage input (TP 0.14-0.41 mg/L vs. 0.02-0.10 mg/L in upstream pool; TKN 2.36-2.44 mg/L vs. 1.10-1.21 mg/L in upstream pool). Other water quality parameters, including temperature, pH, and salinity did not show any pattern consistent with level of development. Island development may impact tropical streams with regard to excessive nutrient input and introduction of exotic species. The amphidromous lifecycle of native shrimps and fishes and its effect on stream colonization are likely to increase natural variability to the animal community present in gut streams. This could serve to protect streams against permanent loss of species if conditions were to become uninhabitable at any given time.

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INTRODUCTION

Background

There has been considerable effort in the US Virgin Islands (USVI) to document and map watersheds and wetlands (e.g., Knowles and Amrani, 1991; Stengel, 1998; Island Resources Foundation, 2004; Platenberg, 2006). St. Thomas has limited natural freshwater resources, represented by man-made agricultural ponds and a small number of riparian stormwater corridors known locally as "guts". Prior to this study, there had been little work documenting the species composition and its variation among different guts.

On St. Thomas, the terrain is characterized by steep hillsides with thin soils and a low permeability of underlying rock. As such, rainfall tends to run down hillsides over the surface through gut channels (Jarecki and Walkey, 2006). Native plant communities along these guts are more mesic than the surrounding upland vegetation, despite that the majority of these guts carry water only seasonally, and flows vary dramatically with rainfall levels. Several species of freshwater fishes and shrimps have been observed to persist in these habitats (Loftus, 2003; pers. obs.). Non-native species of invertebrates, fish, and amphibians are also prevalent.

The demands for space by a rapidly growing human population of over 100,000 in the USVI have resulted in extensive loss and degradation of natural ecosystems, especially on densely populated St. Thomas. Upland development activities are taking place in an unprecedented manner, resulting in increases in unregulated sediment runoff, in addition to agricultural and road runoff and other sources of contamination.

The guts are the primary channel for moving sediment and non-point source pollution resulting from upland activities into lowland wetlands and the marine environment (Platenberg, 2006). These contaminants have a significant negative impact on the coral reefs and fisheries resources that serve as the backbone of the USVI economy (Division of Fish and Wildlife, 2005). Despite this, there has been little attention paid to the effect of such contaminants on the aquatic species contained within, or the ecological function of, these conduit systems. The freshwater shrimp have a role in reducing sediment in streams (Pringle et al., 1999), and they are particularly vulnerable to anthropogenic activities (Garcia and Hemphill, 2002). It may be that these species and associated communities provide a valuable role as bioindicators of the health of these systems.

Island setting

Situated near the eastern terminus of the Greater Antillean chain of islands in the northern Caribbean Sea, the USVI comprise four major inhabited islands and more than 50 smaller offshore cays. St. Thomas, St. John, and Water Island are the three main northern islands, located on the Puerto Rican Shelf to the east of Puerto Rico, while St. Croix is on a separate shelf to the south. The islands are mostly volcanic in origin, with steep slopes and irregular coastlines. The terrain is characterized by these steep hillsides with thin soils and a low permeability of underlying rock (Jarecki, 2003). The highest elevation is on St. Thomas (474 m), with highest points on St. John, St. Croix, and Water Island being 395 m, 355 m, and 91m, respectively. St. Thomas has an area of approximately 7861 ha, and is the most densely populated of the islands (USDA-NRCS, 1998). The islands are surrounded by coral reefs and seagrass beds.

The climate of the islands is dominated by easterly tradewinds, with poorly defined seasonal variation in rainfall. December/January to April are generally dry months, while May through November are considered wet months. Rainfall is frequently highly localized, with the more mountainous north side of St. Thomas receiving more rainfall than the flatter eastern end.

Guts in the US Virgin Islands

In the USVI rainfall tends to run downhill over the surface rather than through the ground because of the thin soil layer and impermeability of underlying rock. The natural channels formed are from this storm water erosion down steep slopes are locally referred to as guts, and are defined as any stream with a well-defined channel including those that result from an accumulation of water after rainfall. A typical gut is a narrow channel, generally between 1-4 m wide, with a loose rocky or boulder substrate and devoid of understory vegetation (Figure 1). Vegetation communities in guts consist of corridors of mesic vegetation, including broadleafed evergreen trees and wetland herbaceous species such as papyrus *Cyperus* spp. and sedges *Carex* spp. (Thomas and Devine, 2005; Platenberg, 2006).

Figure 1. Typical gut drainage on St. Thomas. Note the absence of vegetative understory, bouldery substrate, and lack of water. Guts fill with water after a significant rainfall event.

Natural springs are generally located in guts, resulting in reliably permanent pools of freshwater. Gut pools provide a rare opportunity for freshwater resources in the USVI, where natural freshwater ponds are lacking. These pools provide habitat for a number of species, including wetland and migratory birds, freshwater shrimp and fish, and amphibians. Historically, guts have been dammed to provide available water for crop irrigation, particularly during the plantation era. Intermittent streams are often supplemented from gray water discharge in residential areas. Only a few of these guts have a direct connection to the marine environment except during storm-induced discharge.

Guts are protected under local regulations (VI Code, Title 12, Chapter 3: Trees and vegetation adjacent to watercourses) that prohibit the cutting or injury of any tree or vegetation within 30 feet of the center or 25 feet from the edge of the watercourse. Additional protection is afforded from efforts to reduce non-point source pollution by the VI divisions of Environmental Protection and Coastal Zone Management.

Rainfall, runoff, and sedimentation

Sediment poses a serious threat to wetlands and the marine environment in the USVI. Construction on hillsides loosens and exposes soils that are carried by runoff water through guts into salt ponds and bays (Ramos-Sharrón and MacDonald, 2005). Sedimentation occurs when soil is eroded from the land surface and is collected and delivered to drainages by rainfall moving over the surface of the ground. Sediment yields on St. John have significantly increased since the 1950s as a result of erosion from unpaved roads (MacDonald et al., 1997; Ramos-Sharrón and MacDonald, 2005).

Rainfall runoff also collects other contaminants from human activities, including pesticides, nutrients, and toxic substances, resulting in non-point source pollution. Leaky septic systems (or direct discharge of sewage) and runoff from animal operations result in high loads of bacterial contamination in gut streams, a main cause of beach contamination after significant rainfall events (Division of Environmental Protection, 2004). In the USVI municipal trash collection dumpsters are located on major roads, often where the guts transect the roads. Wayward trash invariably ends up down in the guts and can be carried directly to the sea in major rainfall events.

The role of guts in the transport of these contaminants to salt ponds, mangroves, and marine environments has been largely overlooked. Sedimentation and contaminants have a severe detrimental effect on the high economically valuable marine resources for tourism and fisheries, and as such the Coastal Zone Management program has strict guidelines to regulate activities occurring in coastal areas in order to protect critical wetland resources. In the USVI, upland activities in the USVI are not included in this program due to a two-tiered system for permitting. This results in unregulated activities that directly impact these critical resources via the guts. There has as yet been no attempt to quantify this impact (Platenberg, 2006).

Overview of impact assessment

We examined three parameters to determine impact of residential and commercial development on gut function: the physical characteristics of gut pools, diversity of freshwater fauna, and chemical characteristics of the water.

Goals and objectives of study

The primary objectives of this study were to:

- Determine if three St. Thomas gut streams varied in water quality and if that correlated with the level of human impact in the surrounding watersheds.
- Identify all aquatic species found in the gut stream habitats and look for distribution patterns with respect to among-gut differences in water quality and human impact.

We tested the null hypothesis that watershed development had no effect on the diversity of fish and shrimp species present.

METHODOLOGY

Watershed and gut selection

Watersheds exhibiting low, moderate, and high disturbance from residential and commercial development were identified using criteria for assessing impairment of watersheds (Island Resources Foundation, 2004). These criteria include percentage of watershed with impairing land uses, presence, condition, and width of wetland buffers, hydrological alteration, vegetation removal, and pollution. Data on these criteria are largely lacking for gut systems, and therefore we conducted site visits to several guts to assess impairment. Guts were also selected for presence of permanent gut pools as available habitat for fish and shrimp. The guts selected for this study are shown in Figure 2 and access to them described in Table 1. Notes on relative water flow and stream condition (clarity, sediment) were qualitatively described. Tree canopy prevented georeference of individual pools.

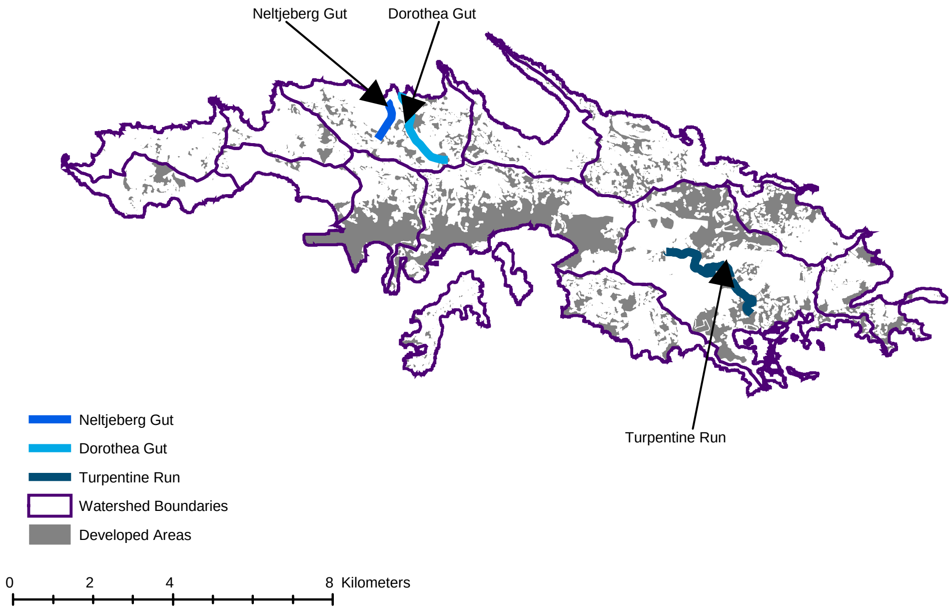


Figure 2. Map of St. Thomas showing the three guts surveyed. Approximate location of pools surveyed is indicated by the arrowhead.

Table 1. Access points to St. Thomas guts surveyed in this study.

Gut	**Development Impact Level**	**Access Coordinates**	**Description of Access**
Neltjeberg	Low	18° 22.077’ N 64° 57.914’ W	upstream of estuary and where lowest residential access road crosses streambed
Dorothea	Moderate	18° 21.767’ N 64° 57.914’ W	up- and downstream of where road (bridge & culvert) crosses over the stream bed
Turpentine Run	High	18° 19.904’ N 64° 53.106’ W	gated access road upstream of where stream first crosses Brookman Road east of Tutu Valley

Gut Stream Fauna Survey

Objectives**:** to identify all aquatic species using the gut stream habitat, and to look for patterns with respect to differences in water quality and land development.

Fish and shrimp were sampled using small aquarium nets, with the observer slowly turning over each rock in the pool to look for shrimp (especially *Macrobrachium* spp.) hiding underneath. Shrimp size and presence of eggs on the abdomen were noted to provide insight into the life history stages present at the various sampling dates. A representative sample of shrimps was collected live and identified using Chase and Hobbs (1969). Subsets of these were preserved as a reference collection (Appendix 1). We recorded the presence of tadpoles, snails, and aquatic insects in the pools, and also opportunistically recorded species that we saw in other pools along the gut.

On one occasion (3 June 2006), plastic funnel traps (minnow traps, baited with canned catfood) were set overnight in the Dorothea gut. The traps captured only a subset of the shrimp species that were visible in the pool, and thus we decided to rely on visual sampling and hand collection of individual organisms for confirmation of their identity.

Water Testing

***Objectives*:** to determine if the gut streams varied in measurements of water quality, and to determine if those parameters varied with respect to our categories of ‘low’, ‘medium’, and ‘high’ relative development.

Nitrogen, Phosphorous, and E. coli

Total Kjeldahl Nitrogen (TKN), Total Phosphorous (TP), and the presence of *E. coli* in the stream water were evaluated on two different dates for all three guts. Water samples were collected in 500ml Nalgene bottles, stored in a cooler on ice, and transported to UVI. Water samples to be evaluated for TKN and TP were stabilized by the addition of 1ml sulfuric acid/500 ml water and refrigerated at 4ºC. TKN and TP tests were performed UVI’s Center for Marine and Environmental Studies using EPA method 351.2 (TKN) and EPA method 365.4 (TP).

The presence of coliform bacteria was determined with an EPA-approved test (Readycult®, available from Merck). This chromogenic enzyme substrate method uses the X-GAL chromogen for detection of the total coliform enzyme (ß-D-galactosidase). The presence of *E. coli* specifically was tested for with the addition of Bactident® Indole Reagent.

In the Dorothea gut, we identified an input of residential sewage that an area resident (Mark Gordon, pers. comm.) said came from a house that had become disconnected from the community septic system. In that gut, we sampled water for TKN, TP, and *E. coli* from pools 20m upstream, and about 20 m and 50m downstream of the sewage input.

Water Quality Characteristics

Temperature, pH, salinity, conductivity, and total dissolved solids were measured with a portable IQ 170multiparameter meter (Figure 3).

To look at daily fluctuations in several water quality parameters, we deployed a YSI water quality meter/data logger system in one of the upper Neltjeberg gut pools March 10-13, 2007. The data logger recorded temperature, pH, total dissolved solids, turbidity, nitrate-nitrogen, and dissolved oxygen.

Rainfall

Rainfall data was acquired and summarized from a weather station located at the top of Crown Mountain (18 ° 21 ' 29 " N, 64 ° 58 ' 21 " W; elevation 421m, St Thomas, VI). Data are available from Weather Underground website at http://www. wunderground.com/weatherstation/ WXDailyHistory.asp?ID=KVISTTHO1.

Figure 3. Water quality parameters were measured using a hand-held meter.

RESULTS

Watershed and gut selection

We surveyed the three guts over a nine-month period (May 2006 to February 2007). Data were collected on three dates per gut, in summer, fall, and winter (Table 2).

Table 2. Dates of data collection at three guts on St. Thomas

Gut	Summer 2006	Fall 2006	Winter 2007
Neltjeberg	7 July 2006	15 October 2006	9 February 2007
Dorothea	15 September 2006	15 October 2006	26 January 2007
Turpentine Run	16 June 2006	17 October 2006	23 February 2007

Neltjeberg (Low Impact)

Neltjeberg Bay is located within the Dorothea watershed (Figure 2, above) in a drainage basin with very low density residential development on the north side of St. Thomas. Three guts drain into Neltjeberg Bay. The easternmost gut, which we sampled, contains a spring and therefore has permanent pools, some of which are several meters across and at least 0.5 m deep (Table 3). Along the segment of the gut surveyed, there is no human encroachment except at the access along a culverted estate road (Figure 4).

During our study, land-clearing and new construction was initiated in the Neltjeberg gut, which may have made it more 'impacted' than our initial designation would lead us to believe. During creation of new driveways, topsoil was dumped directly into the gut (Figure 5) and we saw significant changes in the amount of suspended and benthic sediment in the gut pools after October 2006—especially after heavy rainfall, the stream water was milky brown (Figure 6) making it nearly impossible to visually survey for animals. By February 2007, there was noticeable algal growth and a thick sludge covering bottom in pools.

Figure 4. Representative view of Neltjeberg Gut

Figure 5. Habitat destruction in gut as a result of bulldozing

Figure 6. Increased sediment in gut as a result of upland bulldozing activities

Dorothea (Moderate Impact)

Dorothea Bay is located within the Dorothea watershed in a drainage basin with medium density residential development and agricultural use (Figure 2, above). One major gut drains into the bay; this gut has a persistent stream flow and several large, deep pools (Figure 7; Table 3) with shrimp and fish. Several human encroachments impact the gut along the segment surveyed, including residences with altered vegetation, residential water extraction, a direct sewage input, and a concrete bridge and culvert that spans the watercourse.

One of the most noticeable impacts of human activity on the freshwater community was observed downstream of a residential sewage discharge (Figure 8). Upstream, pool substrate was composed of sand and small rocks, and walking over the substrate did not cloud the water in the pool. Whole leaves were present, but there was almost no fine sediment present. Over 20m downstream of the sewage input, one pool bottom was covered in thick fine mud (over 15cm deep), which released gases from anaerobic bacterial activity and clouds of fine sediment when disturbed. Downstream of the discharge, the pool substrate changed from gravel, to a thick layer of anoxic sludge. The downstream pools were also affected in terms of nutrient load (increased) and native fauna (decreased; see sections below).

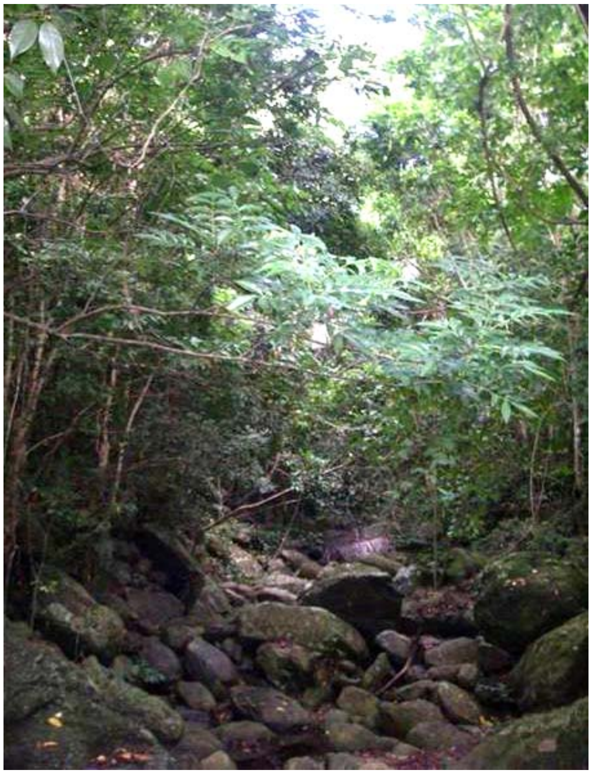


Figure 7. Representative view of Dorothea Gut

Figure 8. Sewage input in Dorothea gut (yellow arrow)

Turpentine Run (High Impact)

This gut is located within the highly developed Jersey Bay watershed on the eastern side of St. Thomas (Figure 2, above). Turpentine Run is the only perennial stream on St. Thomas, although its flow is augmented by water treatment effluent and channelization (Figure 9). Compared to the other two guts, this stream was broader and the pools of much larger volume (Table 3). Intense development in the upper drainage basin has created significant impervious surfaces resulting in increased runoff and channel flow through this gut. Increased sediment loads add to the input of often-polluted water that flows through this channel. Turpentine Run was so polluted at one point that it was designated as an Environmental Protection Agency Superfund site. Since the mid-1990s a major cleanup effort has been underway resulting in a decline in direct contamination from petroleum storage and dry cleaning operations, with treated groundwater being discharged directly into the gut (http://www.dpnr.gov.vi/de/superfund_ program.htm). This has resulted in a steady and often strong stream flow. Although there was no direct human encroachment along the section surveyed, which is below the discharge input, there were considerable levels of trash in and along the stream.

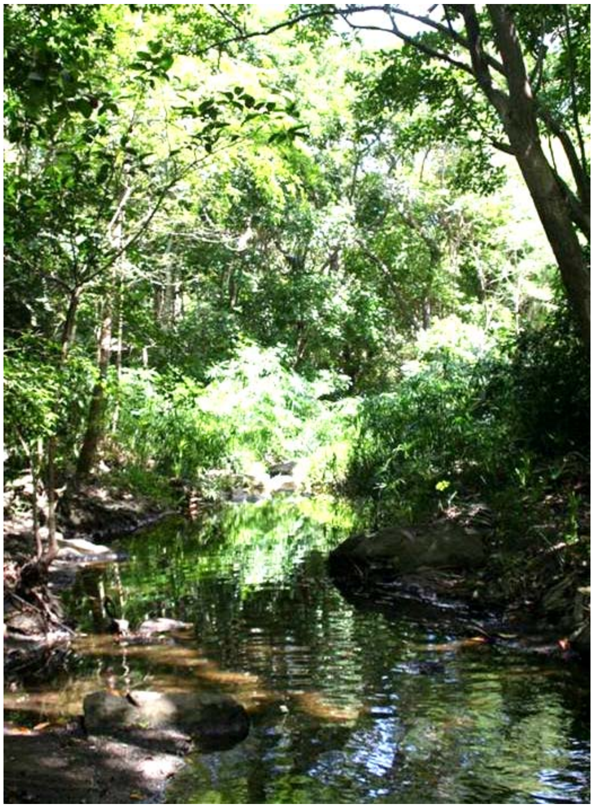


Figure 9. Representative view of Turpentine Run

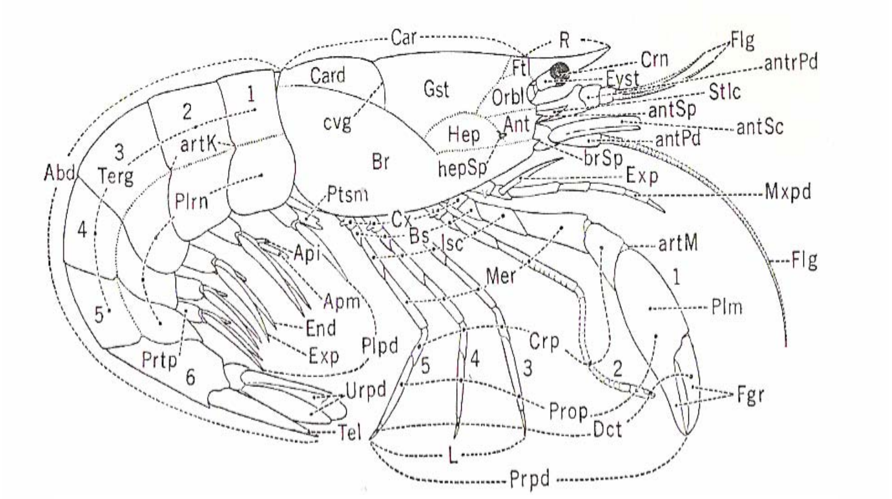
Table 3. Size of gut pools surveyed at each site on dates given below. Pool surface area is calculated as [π(pool width/2)(pool length/2)]. Pool depth is the average of 3 measurements per pool.

	Pool number	Pool surface area (m^2)	Average Pool depth (m)	Pool volume (m^3)
Neltjeberg (7 July 2006)	1	5.70	0.156	1.13
	2	2.44	0.127	0.40
	3	4.91	0.267	1.67
	4	8.48	1.04	11.23
	5	2.11	0.04	0.11
Dorothea (15 Sept. 2006)	1	2.58	1.5	3.04
	2	3.74	1.57	4.61
	3	4.08	4.16	13.32
	4	8.42	4.63	30.60
	5	1.9	1.27	1.89
Turpentine Run (23 Feb. 2007)	1	6.10	1.60	7.66
	2	14.52	4.25	48.44
	3	18.00	6.00	84.78
	4	11.00	2.10	18.13
	5	8.25	3.50	22.67

Gut Stream Fauna Survey

A total of five species of shrimp and four species of fish were located during our survey. Descriptions and an identification guide to shrimp species are provided below, as well as their presence in the three guts (Table 4).

Figures and descriptions below are modified from Chase and Hobbs (1969). This reference includes excellent keys to identification of freshwater crustaceans of the West Indies. Figure 10 is provided as an aid to crustacean anatomical terms.



Abd, abdomen
Ant, antennal region
antPd, antennal peduncle
antrPd, antennular peduncle
antSc, antennal scale
antSp, antennal spine
Apd, apodemal pit
Api, appendix interna
Apm, appendix masculina
artK, articular knob
artM, articular membrane
Br, branchial region
brl, branchial lobe
brSp, branchiostegal spine
Bs, basis
Car, carapace
Card, cardiac region
Crn, cornea
Crp, carpus
cvg, cervical groove
Cx, coxa
Dct, dactyl
End, endopod
epBr, epibranchial region
epGst, epigastric lobe
Epst, epistome
Exp, exopod
Eyst, eyestalk
Fgr, finger
Flg, flagellum
Ft, front
Ftl, frontal region
Gst, gastric region
Hep, hepatic region
hepSp, hepatic spine
Int, intestinal region
Isc, ischium
L, walking leg
Md, mandible
Mer, merus
msBr, mesobranchial region
msGst, mesogastric region
mtBr, metabranchial region
mtGst, metagastric region
Mxpd, maxilliped
Orb, orbit
Orbl, orbital region
Plm, palm
Plp, palp
Plpd, pleopod
Plrn, pleuron
prGst, protogastric region
Prop, propodus
Prpd, pereiopod
Prtp, protopodite
Ptrg, pterygostomian region
Ptsm, petasma
R, rostrum
Stlc, stylocerite
Stn, sternite
Tel, telson
Terg, tergum
urGst, urogastric lobe
Urpd, uropod

Figure 10. Diagrammatic shrimp showing terms used in species descriptions. (Figure modified from Chase and Hobbs, 1969)

Three genera of shrimp from the families Palaemonidae (*Macrobrachium*) and Atyidae (*Atya* and *Xiphocaris*) were collected, comprising a total of five species.

Macrobrachium

The genus *Macrobrachium* contains large predatory shrimp that were predominantly found hiding under rocks during the day. We rarely found more than one individual of *M. carcinus* per gut pool, which is consistent with previous reports that they are territorial and aggressive. During our daytime surveys, often the only evidence that they were present was a freshly molted exoskeleton.

M. carcinus (Figures 11 and 12) can reach a postorbital carapace length of more than 90mm, making it the largest shrimp species found locally. It is distinguished by its elongate claws (second periopods) which are similar in size, and cross at the tips when closed. The carpus is about half as long as the palm, and shorter than the merus. The movable dactyl of the claw has a white spot visible at its base when the claw is open. Both the fixed claw and movable dactyl are armed with a large tooth near midlength (dactyl) or slightly more proximal (fixed finger). The rostrum is dorsally armed with 11-16 teeth. Color varies from blue black to brown, often with longitudinal dark and light stripes on carapace and abdomen.

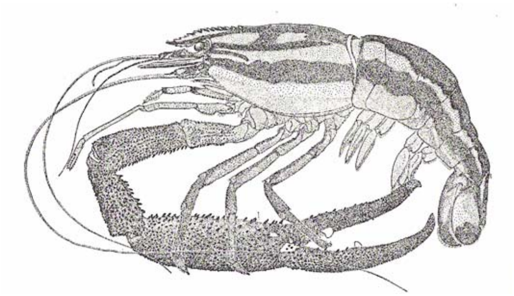


Figure 11. *Macrobrachium carcinus* (figure modified from Chase and Hobbs, 1969).

Figure 12. *Macrobrachium carcinus*

M. faustinum (Figures 13 and 14) was more frequently encountered. Generally we found this species by turning over rocks, but the smaller individuals were often moving around the pool in the open. *M. faustinum* reaches a maximum postorbital carapace length of about 18 mm. It is distinguished from *M. carcinus* in having its second periopods unequal in size. The palm is covered with a soft dense fur, and the fingers of the second periopod show a conspicuous light and dark banding pattern. These bands are visible even in very small individuals that may not yet show a great difference in the shape or size of the two second pereiopods. Juveniles also have the proximal segments of the second and third pereiopods deeply pigmented. The carpus is as long or slightly longer than the palm, and longer than the merus. The rostrum is dorsally armed with 13-15 teeth. Color is a translucent tan, and most individuals show a U-shaped cream-colored bar on the third abdominal tergum.

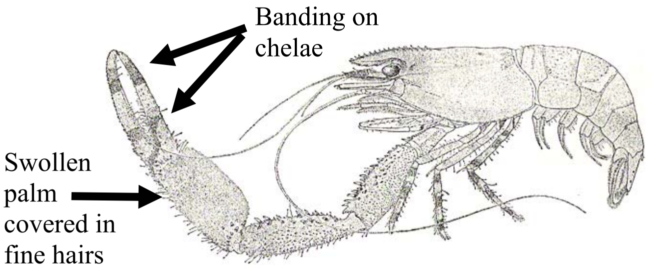


Figure 13. *Macrobrachium faustinum* (figure modified from Chase and Hobbs, 1969).

Figure 14. *Macrobrachium faustinum*

Atya

Atya is distinguished from other St. Thomas shrimps by having the chelae of first and second pereiopods with tufts of long hairs, used in filter-feeding or for 'mopping' the substrate for organic particles (Figures 15 and 16). The hairs can be seen when viewing the shrimp in a clear container of water; in an aquarium, they orient the pereiopods into the water current like a baseball catcher's mitt. The rostrum is unarmed dorsally. *A. lanipes* (Figure 16) has a maximum postorbital carapace length of 28mm. Color is light to dark brown, with the dorsal surface often with a longitudinal darker brown stripe extending from carapace onto abdomen.

A. innocous (Figure 15) is distinct from *A. lanipes* in having the third pereiopods bearing prominent horny tubercles (lacking in *A. lanipes*) and considerably larger and more robust than the fourth pereiopod (only slightly larger in *A. lanipes*). Its maximum postorbital carapace length is 34 mm.

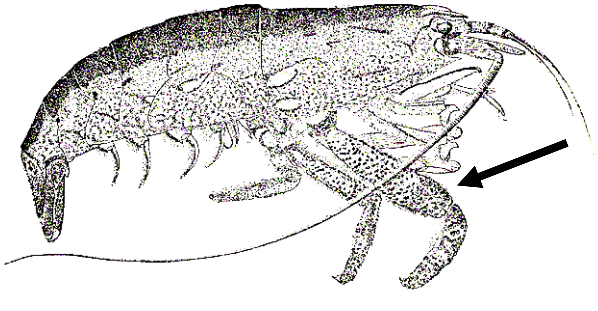


Figure 15. *Atya innocous* (from Chase and Hobbs, 1969). Arrow indicates robust third pereiopod, characteristic of this species.

Figure 16. *Atya lanipes*

Xiphocaris elongata (Figure 17) are a small, slender shrimp often visible swimming in midwater. This species lacks the tufts of hair on the fingers of the chelae of first and second pereiopods (as seen in *Atya*). When netted and lifted out of the water, they actively flexed their abdomens and often flipped themselves out of the net. Maximum size is about 15 mm postorbital carapace length. The rostrum is long and conspicuous (0.8-1.3 times carapace length), with a finely serrated ventral margin. Color is translucent green, with internal organs visible through the carapace.

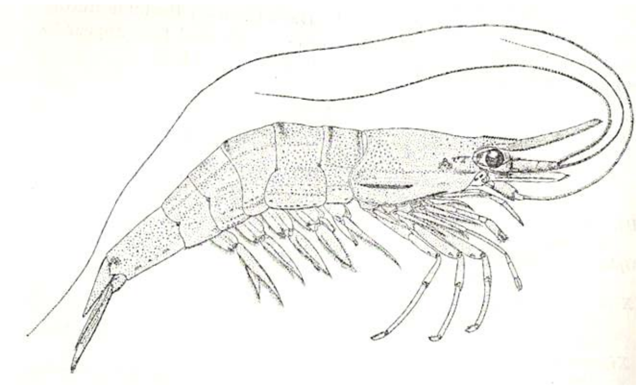


Figure 17. *Xiphocaris elongata* (figure from Chase and Hobbs, 1969).

Fish

Two species of native fish and two non-native species were identified.

The Sirajo Goby (*Sicydium plumieri*) reaches a maximum total length of 7.5-10 cm (Mowbray, 2004), but the maximum size we collected was less than 5cm. Males in breeding coloration are iridescent blue (Figure 18), otherwise individuals are light gray in color. The pelvic fins are fused into a modified suction cup in the characteristic gobiid form, to assist the fish in holding its position on the benthos in flowing water. The Sirajo goby grazes on benthic algae. It is an amphidromous species, with a marine larval phase. They were observed in pools with strong water flow, and we saw up to six individuals in a single pool.

The Mountain mullet (*Agonostoma monticola,* Figure 18), another amphidromous species, can reach a total length of 21 cm (Mowbray, 2004). We observed them in groups of up to six individuals per pool, with the largest individual less than 12cm. Mountain mullet are omnivorous, and in captivity were observed to consume guppies and juvenile shrimp. They also struck at and killed shrimps that were too large for them to swallow.

Guppies (*Poecilia reticulata,* Figure 18) are native to Trinidad, but are common on many Caribbean islands where they were likely introduced for mosquito control.

Tilapia (most likely *Oreochromis* sp.) are African natives that have become widespread throughout the Caribbean where introduced for aquaculture. Although they can survive in seawater, we are unaware of any records of them in the sea surrounding St. Thomas and thus they are likely restricted to the streams where they were introduced.

Figure 18. Sirajo goby *Sicydium plumieri* (left), mountain mullet *Agonostoma monticola* (center), and guppies (*Poecilia reticulata*).

Table 4. Presence of species sampled in low, moderate, and high impact guts.

Species present	**Status**	**Neltjeberg (low)**	**Dorothea (moderate)**	**Turpentine Run (high)**
Shrimp				
Macrobrachium faustinum	Native	X	X	X
Macrobrachium carcinus	Native	X	X	X
Xiphocaris elongata	Native	X	X	X
Atya lanipes	Native	X	X	--
Atya innocous	Native	X	--	--
Fish				
Sicydium plumieri (Goby)	Native	X	X	
Agonostoma monticola (Mountain Mullet)	Native	X	--	X
Oreochromis spp. (Tilapia)	Introduced	--	--	X
Poecilia reticulata (Guppy)	Introduced	--	X	X
Number of species present		**7**	**6**	**6**

Neltjeberg (low impact)

Neltjeberg, the 'low impact' gut, had five species of native shrimps and two native fish species, with no introduced species (Table 4). Neltjeberg was the only gut that contained all the native species found to date on St. Thomas. In Neltjeberg, only 1 individual *Atya innocous* was observed, in June 2006. No other individuals were found on subsequent visits in July & October 2006 and February 2007. *Atya lanipes* shrimp were found bearing eggs on the abdomen in Neltjeberg in July 2007, but not on visits in October 2006 or February 2007.

Other species observed included Cuban treefrogs (*Osteopilus septentrionalis*), the terrestrial soldier crab (*Coenobita clypeatus*), red-footed tortoise (*Geochelone carbonaria*, 1 individual). In the estuarine region of the gut stream, we observed red-ear sardine (*Harengula humerali*), land crab (*Cardisoma guanhumi*), green heron (*Butorides virescens),* and yellow-crowned night heron (*Nyctanassa violacea).*

Dorothea (moderate impact)

Dorothea had four shrimp species, plus the native Sirajo goby and introduced guppies. In Dorothea, a number of ovigerous shrimp species were seen in September 2006: *Macrobrachium faustinum, Atya lanipes* (8-11mm postorbital carapace length); *Xiphocaris elongate* (11-14mm postorbital carapace length). No shrimp were observed with eggs in October 2006 or January 2007. Male Sirajo gobies were observed in bright blue breeding coloration in September 2006. Other species observed included Coqui frogs (*Eleutherodactylus coqui*), Cuban treefrogs (*Osteopilus septentrionalis*), the terrestrial soldier crab (*Coenobita clypeatus*), green iguana (*Iguana iguana*), and dragonfly larvae.

The input of untreated sewage in Dorothea gut was associated with a dramatic change in the fish and shrimp community. Directly upstream of the sewage discharge, gut pools contained 4 species of shrimp (*Macrobrachium carcinus*, *M. faustinum*, *Xiphocaris elongata*, and *Atya lanipes*) as well as the *Sycidium* goby and guppies. Downstream of the discharge, native species of shrimp and fish were absent, with only introduced guppies and Malaysian trumpet snails persisting.

Turpentine Run (high impact)

Turpentine Run had three shrimp species (no *Atya*), the native mountain mullet and two introduced species, guppies and tilapia. In Turpentine Run, Tilapia were observed, and many were constructing depressions in the sand for nesting, in July of 2006. No tilapia were observed on later visits in fall 2006 and winter 2007. None of the shrimps collected in Turpentine Run were observed to be bearing eggs (June, October 2006; Feb. 2007).

Other species observed included native (*Leptodactylus albilabris, Eleutherodactylus antillensis, E. lentus*) and non-native (*Osteopilus septentrionalis*) frogs and green iguanas (*Iguana iguana*).

Water Testing

Nitrogen, Phosphorous, and E. coli

Total Kjeldahl Nitrogen (TKN) and Total Phosphorous (TP) were the only water quality parameters measured that showed an association with human activity. Total Phosphorous concentration was more than four times higher in the most developed watershed (Turpentine Run, 0.17mg/L(Oct) and 0.22mg/L(Feb), Figure 19; Table 5) relative to the least developed gut (Neltjeberg, 0mg/L(Oct) and 0.05mg/L(Feb). Dorothea (medium development) had intermediate levels of TP. In Dorothea gut, the residential sewage discharge provided a reference point for comparison of conditions upstream and downstream of this human impact. Total Phosphorous increased four- to seven-fold at the site of contamination

(0.14mg/L(Oct), 0.41mg/L(Feb)) relative to upstream conditions (0.02mg/L(Oct), 0.10mg/L(Feb))(Figure 20).

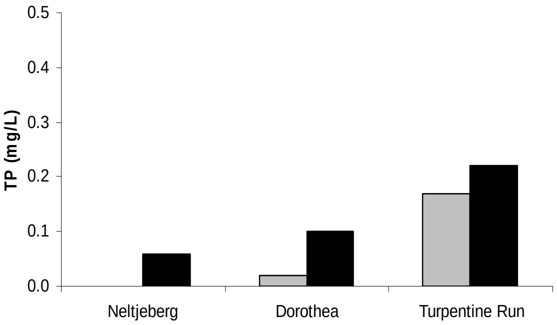


Figure 19. Total Phosphorous in three gut streams in St. Thomas on two sampling dates. Grey indicates October 2006, black February 2007

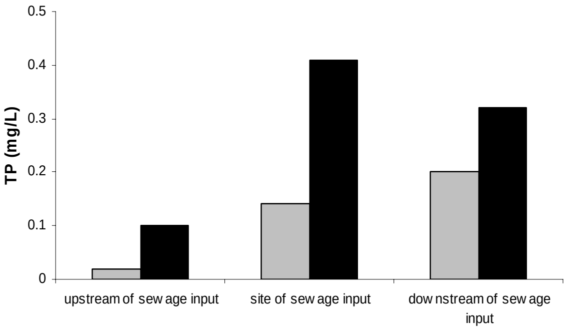


Figure 20. Total Phosphorous in Dorothea gut pools upstream, at, and downstream of residential sewage input on two sampling dates. Grey indicates October 2006, black February 2007

TKN actually decreased slightly with level of development, ranging from 1.28-1.49 mg/L in Neltjeberg (least developed) to 0.84-0.95 mg/L in Turpentine Run (highly developed) (Figure 21; Table 5). However, in Dorothea gut, the residential sewage discharge was associated with TKN levels that more than doubled, from 0.02-0.10 mg/L to 1.1-1.2mg/L downstream of the discharge (Figure 22).

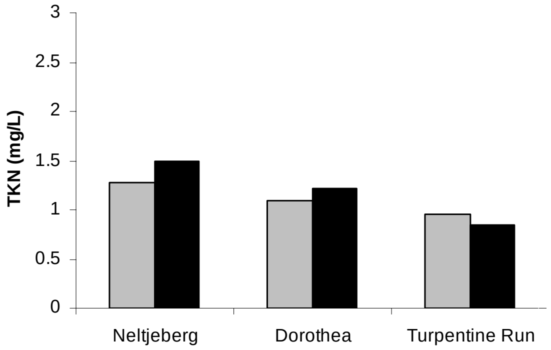


Figure 21. Total Kjeldahl Nitrogen in three gut streams in St. Thomas on two sampling dates. Grey indicates October 2006, black February 2007.

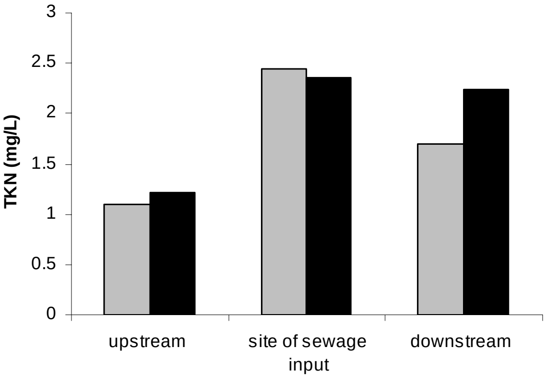


Figure 22. Total Kjeldahl Nitrogen in Dorothea gut pools upstream, at, and downstream of residential sewage input on two sampling dates. Grey indicates October 2006, black February 2007.

Table 5. Total Kjeldahl Nitrogen and Total Phosphorous levels in three gut streams on two dates. For Dorothea gut, additional data are presented for pools at two points downstream of a residential sewage contamination.

	TKN (mg/L) Oct 2006	**TKN (mg/L) Feb 2006**	**TP (mg/L) Oct 2006**	**TP (mg/L) Feb 2006**
Neltjeberg	1.28	1.49	0.00	0.06
Dorothea: upstream of input	1.1	1.21	0.02	0.1
Dorothea: 20m downstream	2.44	2.36	0.14	0.41
Dorothea: 50m downstream	1.7	2.24	0.2	0.32
Turpentine Run	0.95	0.84	0.17	0.22

E. coli was present in all three streams in October 2006 and February 2007.

Water Quality Characteristics

We did not observe any clear differences between the three streams in terms of their temperature, pH, total dissolved solids, conductivity, or salinity. The range and means for water quality parameters for each stream are pooled and shown in Table 6. The data were not statistically compared because we realized that we had not standardized the time of day when the readings were taken, and it became evident that several parameters varied substantially over the time of day. No clear seasonal pattern was seen for pH in the guts (Figure 23). The low pH for Neltjeberg in summer may have been an artifact due to inaccurate meter calibration.

Table 6. Average water quality parameters (n=15 per gut, average of data from 5 pools on three dates, ± sd.

	pH	**Temperature (°C)**	**TDS (ppm)**	**Salinity (ppt)**	**Conductivity (µS)**
Neltjeberg	7.19±0.99	26.09±0.83	389±420	0.99±0.44	134±294
Dorothea	7.85±0.31	25.3±1.3	232±213	0.20±0.22	246+397
Turpentine Run	7.68±0.39	26.50±0.86	343±68	0.34±0.07	626±95

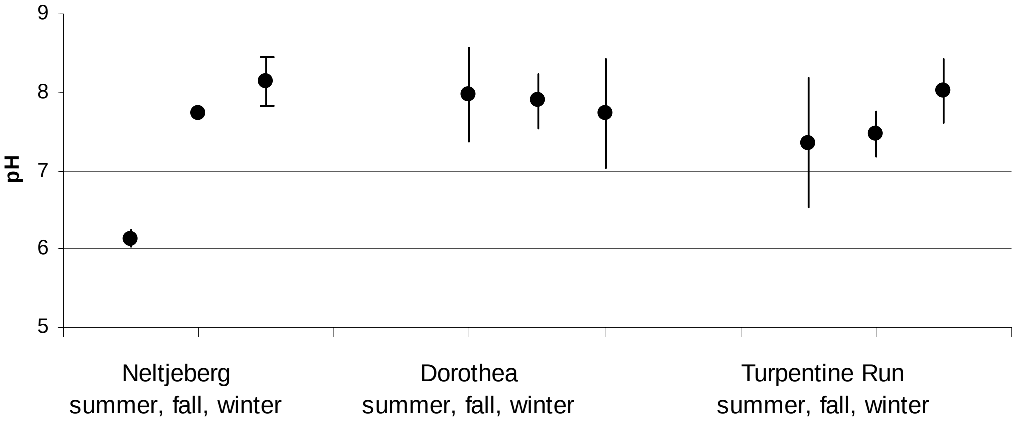


Figure 23. Mean pH of gut stream pools was variable and showed no consistent trends among season or site (n=5 pools per stream, except for Neltjeberg fall (n=1). Error bars indicate 2 standard deviations from the mean (approximate 95% CI).

Data from the YSI water quality meter/data logger allowed us to look at variation in water quality parameters over a three day period. Temperature and dissolved oxygen showed daily cycles, increasing mid-day and falling at night; turbidity showed the reverse, with highest turbidity recorded at midnight (Figure 24). pH was somewhat cyclical with higher mid-day values, yet showed a lot of variability over the 3-day period (mean pH 7.74±0.08, range 7.54-7.89). Nitrate-Nitrogen also showed a daily cycle, tending to be higher mid-day (Figure 25) (mean 8.05±0.38 mg/l). Where TKN includes ammonia plus organic nitrogen, Nitrate-Nitrogen measures a different form of inorganic nitrogen.

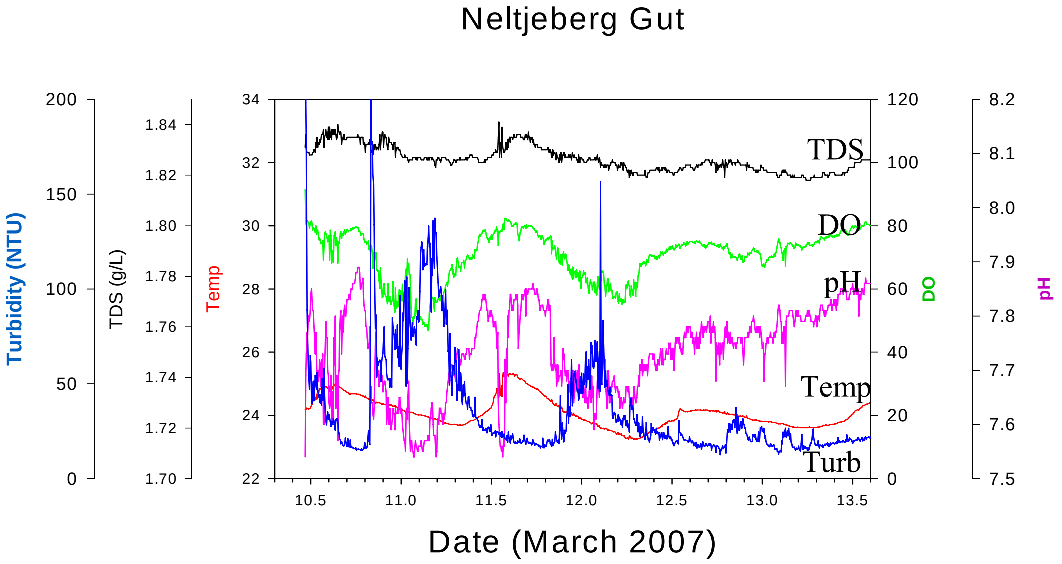


Figure 24. Water quality parameters from a YSI water quality meter/data logger system in one of the upper Neltjeberg gut pools March 10-14, 2007. A date of '10.5' indicates a time of noon on March 10, '11.0' indicates midnight of March 10, etc.

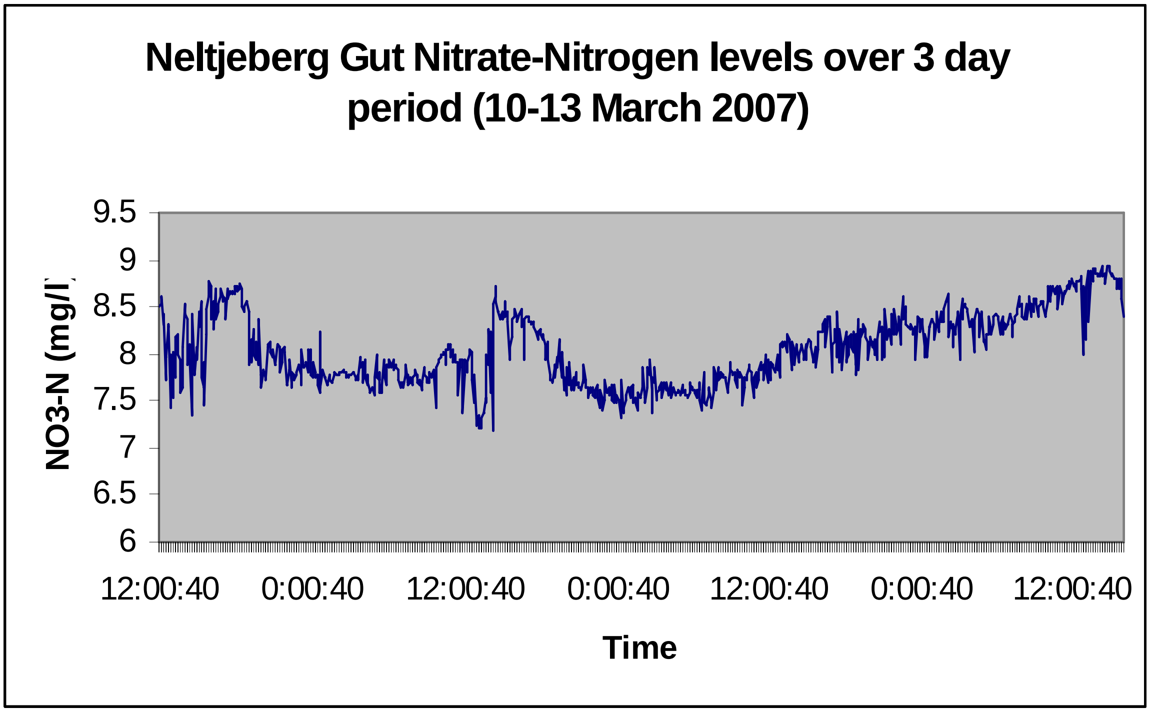


Figure 25. Nitrate-Nitrogen readings from a YSI water quality meter/data logger system in one of the upper Neltjeberg gut pools March 10-14, 2007. The first time of "12:00:40" refers to noon on March 10; remaining times are listed as 12 hour intervals from that start time.

Rainfall

The Virgin Islands experience two rainy periods during the year, in April- May and again in October-November. February and March are typically the driest months. Average annual rainfall in St. Thomas is 97.4 cm. (http://www.vinow.com/usvi/weather.php#rain).

In October, the heavy rains (Figure 26) were associated with slightly greater water flow in the three guts. In Turpentine Run, we saw evidence of flash flooding—papyrus plants along stream margin were flattened against the banks, and we could see where the water flow has come up the banks at least 50cm vertically in some areas (Figure 27). In Turpentine Run, the water was foamy, and brown with suspended sediment.

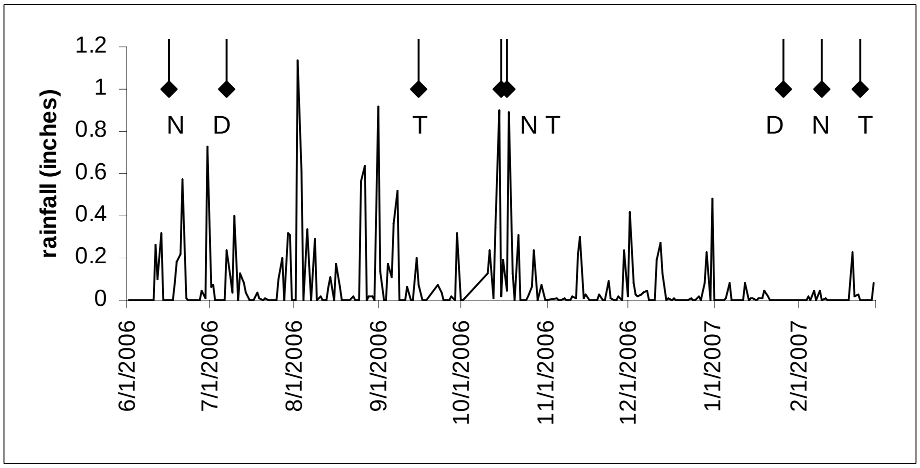


Figure 26. Daily rainfall recorded on Crown Mountain, St. Thomas, during study period. Arrows depict date of sampling. D = Dorothea, N = Neltjeberg, T = Turpentine Run.

Figure 27. Evidence of heavy rainfall event in Turpentine Run. Note brown water color and flattened vegetation

DISCUSSION

We tested the null hypothesis that watershed development had no effect on the diversity of fish and shrimp species present. Although our observations are limited in scope both along each watershed and in number of sampling dates, we see several trends that support our hypothesis and suggest further study.

Organic pollutants were the most informative in terms of correlating water quality with the human impact. According to the U.S. Environmental Protection Agency (http://www.epa.gov/waterscience/criteria/nutrient/), "Nutrients, nitrogen and phosphorus, have consistently ranked as one of the top three causes of use impairment in US waters for more than a decade." Sources of these organic compounds can include human and animal waste, or fertilizers, which are likely to enter gut streams in areas where sewage treatment is absent or poorly maintained, or in areas where there is heavy agricultural activity. Excess Phosphorous and Nitrogen can negatively impact freshwater habitats through their promotion of harmful algal growth and subsequent hypoxia as the algae decompose.

Total Phosphorous levels increased with relative amount of watershed development. Turpentine Run receives effluent from a number of commercial businesses in the Tutu area of St. Thomas, including laundries, which could account for high phosphorous input. Both TP and TKN increased downstream of a residential sewage input in Dorothea gut. This input of organic material resulted in the accumulation of fine sediments where anaerobic bacteria and blue-green algae thrived; no shrimp or gobies were observed in this area despite their persistence in the pools upstream throughout the duration of our study. Atyid shrimps (*Ayta* and *Xiphocaris*) have been shown to reduce sediment loads in stream pools (Pringle et al., 1993). Thus, if they are unable to inhabit, or avoid, pools with high organic pollution, such streams may lack natural controls to reduce the impact of added nutrients. The presence of the introduced guppies and trumpet snails in the polluted pools may reflect a greater tolerance of environmental conditions by such species. The population density of these exotics was dramatically higher (thousands of individuals in pools less than a meter diameter) in the polluted pools relative to other areas where they were observed. Malaysian trumpet snails feed on algae and dead plant material, but avoid other live plants (Avila, 2007) —thus, they may actually mitigate some of the impacts of pollution.

The U.S. Environmental Protection Agency website (http://oaspub.epa.gov/nutdb/reports.control, 2006) provides water quality criteria by state/ecoregion, and we found average values for TKN and TP for a number of Puerto Rico counties, which we provide to give some relevant context to our measurements. Over all the counties, TKN ranged from 0.05 to 5.27 mg/L (mean: 0.50mg, N=494 observations—compare to our data, where TKN ranged from 0.8-2.4 mg/L); TP ranged from 0.0025 to 2.4 mg/L (mean: 0.16 mg/L, N=585 observations—compare to our data, where TP ranged from 0.0-0.4 mg/L).

The presence of *E. coli* in the streams could result from either human or animal waste contamination. Its presence in all three guts likely results from lack of proper sewage treatment and containment in residential systems, as well as proximity of livestock to the streams.

Streams with the greatest level of development had fewer fish and shrimp species. Non-point source pollution or the introduction of other contaminants could reduce the habitability of the other two streams for certain native species. Our observations that the habitat downstream of a residential sewage leak was severely modified in nutrient load, had heavy sediment accumulation, and lacked native species in pools immediately downstream, provided the clearest support for the potential impact of nutrient loading. The only species present in those areas were guppies, and an introduced Malaysian trumpet snail (*Melanoides tuberculata*) that feeds on dead and decaying organic matter. Atyid shrimps (*Atya* and *Xiphocaris)* are known to significantly reduce the accumulation of benthic sediments, which affects community structure through allowing higher biomass of algae and benthic insects (Pringle et al., 1993). Thus, the absence of such species can have a major impact on the entire community food web structure.

Human activity can also impact the ability of native species to colonize streams and maintain stable populations. We had heard of one example in which landowners had filled estuarine pools with soil, supposedly to reduce mosquito breeding populations. However, this also effectively interrupted water flow between the gut and sea. Since all the native shrimps and fish are amphidromous, this would also prevent the movement of eggs, larvae, or juveniles between the freshwater and marine environments. Studies by Garcia and Hemphill (2002) in Puerto Rico have expressed concern over the potentially devastating effect humans can have on freshwater shrimp populations, through damming, loss of estuarine nursery habitat from development and water contamination, and the effects of over harvesting. A case study involving chemical poisoning of the Espiritu Santo River found that *Atya* shrimp populations did not recover for 2 years due to lack of recruitment (Greathouse et al., 2005).

Streams with the greatest level of development had introduced species present. The presence of two non-native fish species in the mid and high impact guts also supports our hypothesis that human impact can modify stream communities. Guppies, which were likely introduced for mosquito control, would have been placed in streams near where humans would encounter heavy mosquito populations. Tilapia have been brought to the VI for aquaculture, and may have been accidentally or intentionally released in some streams and ponds. Both fish species have the potential to prey on other native species and their larvae, or to compete with them for food resources. Malaysian trumpet snails were present in all three guts, and could have been introduced with imported aquatic plants.

***Atya* shrimps may be useful as a bioindicator in tropical freshwater streams.** In our study, the shrimps either actively avoided pools with high organic loads (TKN and TP) or could not survive there. Shrimp do not tolerate low dissolved oxygen levels, which would be a likely consequence of the high organic load. In addition, *Atya* was not found by us in Turpentine Run—is its absence a consequence of higher phosphorous levels in that gut, other chemical pollutants, or random colonization? More work is necessary to examine the sensitivity of different species to pollutants and changes in water quality. Alternatively, the introduction of Tilapia, potential predators, could reduce the ability of these shrimps to successfully colonize or persist in that stream.

FUTURE RESEARCH DIRECTIONS

Future studies should account for seasonal variability in water flow and continuity of the estuary. There is likely a component of chance as to what species may be found in a given watershed, because all the native fish and shrimp species are amphidromous, with a marine larval phase. Because of the high variability in rainfall and water flow throughout the year, the guts do not always maintain access to the sea for larval shrimp or fish to enter (personal observation). Thus, there is likely to be high natural variability in terms of a given species finding a particular stream at the correct time in its larval development. The fact that some species may migrate downstream to release eggs from a point closer to the sea (Bauer, 2004) could account for the apparent disappearance from some study pools in the autumn and winter. Future studies should consider surveying the entire stream more extensively along its length to address population variation associated with migrations associated with reproduction and colonization.

We recognize that there are many other potentially productive research questions that remain to be addressed regarding the freshwater community and its response to human disturbance of the watershed ecosystem.

The dynamic nature of the gut system is such that periodic visits should be frequent enough to detect within season variations. Weekly site visits should be conducted to determine how rainfall, evaporation, and flow affect species persistence and response. Although guts with persistent pools are relatively rare in the USVI, sampling should be extended to include more guts within more watersheds to eliminate bias of single disturbance events (such as the sewage outflow in Dorothea and the upland development at Neltjeberg). Sediment levels in gut pools should be systematically measured. Laboratory studies should be conducted to determine species response to contaminants and to non-native species. Gut sampling should also be extended to include insect fauna.

In addition, while territorial conferences on non-point source pollution as well as numerous marine outreach programs on the fragility of the marine environment have sought to educate schoolchildren and the voting populous, the more cryptic freshwater gut environments are largely unappreciated for their ecological value and their sensitivity to anthropogenic factors. There is a great need for public education, including lawmakers, to ensure that development and zoning can proceed in an environmentally-agreeable manner.

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Duvané Hodge and Donna Nemeth searching for shrimp in Turpentine Run

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Appendix 1. Animal specimens preserved in 70% ethanol as a reference collection. Specimens stored in UVI MacLean Marine Science Center.

Species	**# specimens**	**Location**	**Date collected**
Agonostoma monticola	1	Neltjeberg gut	9 June 2006
Atya innocous	1	Neltjeberg gut	9 June 2006
Atya lanipes	1 molt	Dorothea gut	May 2006
Atya lanipes	3	Dorothea gut	26 May 2006
Macrobrachium carcinus	Molted claws only	Dorothea gut	26 May 2006
Macrobrachium carcinus	1 molt	Neltjeberg gut	9 June 2006
Macrobrachium faustinum	2	Turpentine Run gut	26 May 2006
Macrobrachium faustinum	1 (ovigerous)	Dorothea gut	3 June 2006
Macrobrachium faustinum	3 (juveniles)	Neltjeberg gut	9 June 2006
Macrobrachium faustinum	1	Turpentine Run gut	26 May 2006
Macrobrachium faustinum?	4 (juveniles)	Neltjeberg gut	29 June 2006
Sycidium plumieri	1	Neltjeberg gut	9 June 2006
Xiphocaris elongata	1	Dorothea gut	3 June 2006
Xiphocaris elongata	1 (juvenile)	Neltjeberg gut	9 June 2006
Xiphocaris elongata	7 (1 ovigerous)	Dorothea gut	26 May 2006