Name of Project: **Establishing TMDLs to address wet weather flow impacts, pathogens, and NPDES program strategies in a priority urban watershed – Kaelepulu, Hawaii – Biological Survey**

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This report addresses Objective 4 of the current project and that is to "Identify the occurrence, distribution, and life cycle status of existing biota in the inland brackish waters." This was accomplished by conducting a biological assessment which is an evaluation of the condition of a waterbody using biological surveys and other direct measurements of the resident biota in surface waters. The survey was done between March 1- 8, 2012. The procedures followed were modified from Barbour, et al., (1999) entitled, Rapid Bioassessment Protocols (RPBs) for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish[1]. The RBPs are essentially a synthesis of existing methods that have been employed by various other State Water Resource Agencies.

Sampling Sites: A total of seven sampling sites were visited during the reporting period and their GPS coordinates are provided in Table 1. In addition, the closest sampling sites from which water quality data were obtained over the course of the entire year is also provided. A Google Earth image (Figure 1) is also provided that identifies that various sampling sites visited for the biological survey.

[1] http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm

Table 1. Location of the sampling sites from which data for the biological survey were obtained.

Biological Survey Site	Latitude	Longitude	Closest Water Quality Sample Station
Site 1	21° 24.346"N	157° 45.357"W	51
Site 2	21° 23.380"N	157° 44.426"W	45
Site 3	21° 23.774"N	157° 43.665"W	76
Site 4	21° 23.359"N	157° 43.744"W	65
Site 5	21° 22.724"N	157° 43.934"W	9
Site 6	21° 23.039"N	157° 44.058"W	35
Site 7	21° 22.674"N	157° 44.405"W	2

Figure 1. Sites at which data for the biological assessment was obtained during the current study.

Methods: Sample sites #1. 2 and 3 were obtained by wading along the shore bank while the remaining sample sites were accessed by boat. Sampling at sites #4 – 7 were also done from the boat.

The macro-invertebrate survey was conducted by Clyde Tamaru and Dr. David Bybee (Figure 2), assistant professor at Bringham Young University Hawaii. Dr. Bybee received his doctorate from the University of Hawaii at Manoa from the Department of Zoology and specialized in characterizing the reproduction and early life history of polychaete worms. Dr. Bybee identified the specimens obtained into the various invertebrate taxonomic groups that is used in the RPB assessment in the field. Two collection methods were used and included a core of the sediment using a 2.5 inch pvc pipe. Contents were sieved threw a pan equipped with a 500 µm screen. The second utilized hand held dip nets that were taken at multiple samples (n= 5) along a 100 meter stretch of the sample site. Visual sightings were also used as a means of detecting the presence of macroinvertebrates throughout the sampling sites.

Figure 2. Dr. David Bybee using two collection methods for conducting the Macro-invertebrate survey.

The Habitat Assessment Field data sheet for low gradient streams was used as a template for obtaining field data, although not all parameters could be used as clearly many segments of the study area are not stream-like. However, for those that were found to be applicable for assigning a score for the habitat assessment, consensus from both investigators was needed to decide on a particular score for the various parameters.

Dissolved oxygen was measured using a YSI 55 dissolved oxygen meter that is also capable of measuring water temperature. The DO meter was calibrated according to the manufacturer's instructions just prior to being taken into the field and used throughout the day. pH was measured using a PinPoint® pH meter (American Marine Inc.) that was calibrated using a 4.0 and 7.0 standard provided by the manufacturer just prior to being taken into the field and used throughout the day. Conductivity was measured using a PinPoint® Conductivity meter that was calibrated according to the manufacturer's instructions and standard provided with the instrument. Calibration was done just prior to being taken into the field and used throughout the day.

Macroalgae distribution was made by visual assessment with the aid of a one square foot pvc quadrat. The amount of coverage within the quadrat was used to estimate the percent coverage of the bottom. Algae samples that were collected were identified by Vernon Sato, Aquatic Biologist (retired) formerly with the Division of Aquatic Resources Department of Land and Natural Resources.

The fish survey was conducted by Clyde Tamaru between March 1-2 and 8, using a combination of cast net 14' diameter with 3/8" (9.6 mm) mesh size and by visual identification. Three casts were made along the 100 meter sections that make up the sample sites. Fish were placed into a 40 gallon tub filled with water and the number of fish scooped out with a dip net counted and identified in the field and released. Photographs of each species collected were made and is provided in the Appendix. Four species that were visually identified required images to be

retrieved from the internet using the following websites:
http://www.marinelifephotography.com/ (*Arothron hispidus*)
http://www.sms.si.edu/irlspec/Gambusia_affinis.htm (*Gambusia affinis*).
http://en.wikipedia.org/wiki/File:Barracuda_laban.jpg (*Sphyraena barracuda*)
http://www.marinelifephotography.com/fishes/mullets/atherinomorus-insularum.htm
(*Atherinomorus insularum*). A fifth species that was visually identified was the milkfish, *Chanos chanos* and a stock photograph from the PI's collection was used in the data set.

I. <u>Physicochemical Parameters</u>

The physiochemical parameters that were present at the various sampling sites obtained during the survey that was conducted on March 8, 2012 is presented in Table 2. Heavy rains that had occurred prior to the sampling accounts for the low conductance/salinity observed at all of the sampling sites with the exception of Site #3. This site is located across from Buzz's Steakhouse and the higher salinity is due to the influx of seawater that is occurring due to the opening of the sand dune that usually blocks exchange of water with the sea. The overall pattern of differences in water quality parameters throughout the sample sites remains the same with low dissolved oxygen levels being recorded at sample sites # 1 and 2. The levels recorded during the survey are actually higher than the normal levels that were recorded over the course of an entire year and no doubt being impacted by the lower salinity due to the additional rainfall. The low salinity observed at sample site #7 is also lower than normally observed (range 11-18 ppt) and likewise is being impacted by the rain as the site is downstream of the major freshwater input site for the lake. None the less the physiochemical data clearly points out that there are variations in habitat throughout the study area.

Table 2. Water quality parameters at various sample sites at the time of biological survey.

Location	Water Temp (C)	Conductance mS/cm	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	Turbidity
Site 1	21.0	4.0	2.1	0.95	7.62	Opaque
Site 2	22.1	4.9	2.7	1.53	7.43	Opaque
Site 3	22.5	44.6	29.0	6.50	7.98	Opaque
Site 4	22.1	16.8	10.0	6.22	7.72	Opaque
Site 5	22.3	16.6	9.7	5.53	7.79	Opaque
Site 6	23.2	19.5	12.0	5.57	7.86	Opaque
Site 7	22.5	7.4	4.2	3.45	7.57	Opaque

II. <u>Habitat Assessment</u>

As part of the habitat assessment the surrounding landscape and its uses are important considerations. A summary of those parameters for the various sampling sites is summarized in Table 3. Clearly the surrounding landscape for the area is predominantly surrounded by man-made activities.

Table 3. Predominant surrounding landscape use.

Location	Forest	Field/Pasture	Agriculture	Residential	Commercial	Industrial
Site 1		X				
Site 2		X			X	
Site 3				X	X	
Site 4				X		
Site 5				X		
Site 6				X		
Site 7				X		

Another parameter used in the assessment of habitat is the odor of the surrounding water of the sample site. A summary of the results obtained are provided in Table 4. For most of the sites sampled there were no discernible odors originating from the surrounding water. However this was not the case at sites # 6 and #7. At both of these locations there was a "fishy" smell that emanated from the surrounding water. It is noteworthy to mention that at site #7 there was a noticeable fish kill that had apparently occurred recently with approximately 100 tilapia individuals littering the bottom. The corresponding low dissolved oxygen levels (i.e., 3.45 ppm, Table 2) indicates a possible cause for the fish kill although it is still much higher than what the species is known to be able to tolerate. Both observations, however, indicate areas that are clearly being impacted.

Table 4. Odors from surrounding water.

Location	Normal/None	Petroleum	Fishy	Sewage	Chemical	Other
Site 1	X					
Site 2	X					
Site 3	X					
Site 4	X					
Site 5	X					
Site 6			X			
Site 7			X			

The odor of the sediment/substrate when it is disturbed is also used as a parameter of the assessment process. A summary of the results obtained for the various sampling sites is provided in Table 5. At all sites the sediment had the characteristic rotten egg smell of hydrogen sulfide indicating the existence of anaerobic conditions. However, at site number 6 a foul odor that was characterized as sewage was also scored. Whether this indicated the actual existence of sewage was not determined. The results also are clear indicators of an impacted water body and in this instance clearly throughout the entire study area.

Table 5. Odors from sediment/substrate.

Location	Normal	Chemical	Sewage	Anaerobic	Petroleum	Other
Site 1				X		
Site 2				X		
Site 3				X		
Site 4				X		
Site 5				X		
Site 6			X	X		
Site 7				X		

The nature of the deposits that make up the sediment/substrate are also used as an assessment tool and the data obtained from the various sampling sites are summarized in Table 6. Interesting there is a clear trend in the distribution of "sludge" that makes up the deposits in the sediment as it moves from the tributaries and into the lake itself.

Table 6. Deposits in the sediment/substrate.

Location	Sludge	Sawdust	Paper Fiber	Sand	Relict Shells	Other
Site 1				X	X	coral
Site 2				X	X	
Site 3				X		
Site 4	X					
Site 5	X					
Site 6	X					
Site 7	X					

A simple tool of assessing habitat is to examine the color of stones that are not deeply embedded in the surrounding substrate. In Table 7 the results of that examination are presented for each of the sampling sites. In all cases the undersides of the stones were found to be black in color and this results is consistent with that obtained in Table 5 indicating anaerobic conditions in the bottom sediments in all locations.

Table 7. Undersides of stones are black in color?

Location	Yes	No
Site 1	X	
Site 2	X	
Site 3	X	
Site 4	X	
Site 5	X	
Site 6	X	
Site 7	X	

The composition of the substrate was examined visually and an estimate of the percent composition was made and the results summarized in Table 8. There is a clear trend in the increase in amount of silt that contributes to the composition of the substrate as the sampling sites move in a southerly direction.

Table 8. Inorganic substrate components (% composition)

Location	Bedrock	Boulders	Cobble	Gravel	Sand	Silt	Clay
Site 1			20	10		70	
Site 2				40	20	40	
Site 3					100		
Site 4						100	
Site 5					10	90	
Site 6						100	
Site 7						100	

A summary of the organic composition of the substrate at the various sample sites is provided in Table 9. As with the inorganic components there is a clear trend of an increase in mud and muck contributing to the bottom substrate with sites 5-7.

Table 9. Organic substrate components (% composition)

Locations	Detritus	Muck-Mud	Grey-Shell Fragments
Site 1	10	70	20
Site 2	30	70	0
Site 3	75	25	0
Site 4	80	20	0
Site 5	0	100	0
Site 6	0	100	0
Site 7	0	100	0

The rationale to use the Epifaunal Substrate/Available Cover as an assessment parameter is that a wide variety and/or abundance of submerged structures in the stream/canal provides macroinvertebrates and fish with a large number of niches, thus increasing habitat diversity. As variety and abundance of cover decreases, habitat structure becomes monotonous, diversity decreases, and the potential for recovery following disturbance decreases. Four scores were available to choose from that summarizes the current state at the respective sample sites. That data which consensus between the two investigators needed to agreed upon is summarized in Table 10. Only sites 3, 4 and 5 received scores that were marginal with the remaining sites all receiving a poor ranking. In short, very little in the way of habitat diversity is available throughout the study area.

Table 10. Epifaunal substrate and available cover.

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1				X
Site 2				X
Site 3			X	
Site 4			X	
Site 5			X	
Site 6				X
Site 7				X

Channel alteration is a measure of large-scale changes in the shape of a stream channel and many streams in urban and agricultural areas have been straightened, deepened, or diverted into concrete channels, often for flood control or irrigation purposes. Such streams have far fewer natural habitats for fish, macroinvertebrates, and plants than do naturally meandering streams. Channel alteration is present when artificial embankments, and other forms of artificial bank stabilization or structures are present and when the stream is very straight for significant distances. A summary of this parameter for the various sample sites is provided in Table 11. A poor rating consists of banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Although certain sample sites (e.g., #5, #6 and #7) clearly are not streams or even stream like they are being included in the assessment as the shorelines for each of the sampling sites clearly fit the criteria for the poor rating.

Figure 3. Sample Site #2 of the biological survey.

Table 11. Channel alteration

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1				X
Site 2				X
Site 3				X
Site 4				X
Site 5				X
Site 6				X
Site 7				X

Channel sinuosity evaluates the meandering or sinuosity of a stream. A high degree of sinuosity provides for diverse habitat and fauna and bends protects the stream from excessive erosion and flooding and provides refugia for benthic invertebrates and fish during storm events. However, all of the sampling sites (Table 12) received a poor rating as the tributaries all have been channelized.

Table 12. Chanel sinuosity.

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1				X
Site 2				X
Site 3				X
Site 4				X
Site 5				NA
Site 6				NA
Site 7				NA

NA = not applicable

Bank stability measures whether the stream banks are eroded (or have the potential for erosion). Steep banks are more likely to collapse and suffer from erosion than are gently sloping banks, and are therefore considered to be unstable. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil. Eroded banks indicate a problem of sediment movement and deposition, and suggest a scarcity of cover and organic input to streams. Each bank is evaluated separately and the data are summarized in Tables 13a and b. The majority of the sampling sites received a suboptimal to optimal rating and for both banks. So despite the low number of bends in the banks mainly due to human intervention the banks of the shoreline appear to be well stabilized in most cases.

Table 13a. Bank stability (Mauka or Left Bank)

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1		X		
Site 2		X		
Site 3			X	
Site 4		X		
Site 5	X			
Site 6	X			
Site 7	X			

Table 13b. Bank stability (Makai or Right Bank)

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1		X		
Site 2		X		
Site 3			X	
Site 4		X		
Site 5	X			
Site 6	X			
Site 7	X			

Bank vegetative protection measures the amount of vegetative protection afforded to the stream bank and the near-stream portion of the riparian zone. The root systems of plants growing on stream banks help hold soil in place, thereby reducing the amount of erosion that is likely to occur. This parameter supplies information on the ability of the bank to resist erosion as well as some additional information on the uptake of nutrients by the plants, the control of in stream scouring, and stream shading. Banks that have full, natural plant growth are better for fish and macroinvertebrates than are banks without vegetative protection or those shored up with concrete or riprap. This parameter is made more effective by defining the native vegetation for the region and stream type (i.e., shrubs, trees, etc.). In some regions, the introduction of exotics has virtually replaced all native vegetation. The value of exotic vegetation to the quality of the habitat structure and contribution to the stream ecosystem must be considered in this parameter. The results of the survey are presented in Tables 14a and 14b and the ocean side banks of Sites #1 and #2 received a higher rating than did any of the other sites. Site #1 is benefiting from a bank restoration effort using native plants and a major reason for the high rating. The mountainside bank for Site #2 benefits from a wetland restoration effort focused on providing habitat for native Hawaiian waterfowl. However, in this case the vegetation is largely non-native species but still results in providing good coverage and habitat for the birds and potentially some fish as well.

Table 14a. Vegetative protection (Mauka or Left Bank)

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1				X
Site 2		X		
Site 3				X
Site 4				X
Site 5				X
Site 6				X
Site 7				X

Table 14b. Vegetative protection (Makai or Right Bank)

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1		X		
Site 2				X
Site 3				X
Site 4				X
Site 5				X
Site 6				X
Site 7				X

Riparian vegetative zone width measures the width of natural vegetation from the edge of the stream bank out through the riparian zone. The vegetative zone serves as a buffer to pollutants entering a stream from runoff, controls erosion, and provides habitat and nutrient input into the stream. A relatively undisturbed riparian zone supports a robust stream system; narrow riparian zones occur when roads, parking lots, fields, lawns, bare soil, rocks, or buildings are near the stream bank. Residential developments, urban centers, golf courses, and rangeland are the common causes of anthropogenic degradation of the riparian zone. Data obtained for the various sample sites are summarized in Tables 15a and 15b and wth the exception of Site #1 seaside bank, all sites received a poor rating which is consistent with a riparian zone of less than 6 meters and; little or no riparian vegetation due to human activities.

Table 15a. Riparian vegetative zone width (Mauka or Left Bank)

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1				X
Site 2				X
Site 3				X
Site 4				X
Site 5				X
Site 6				X
Site 7				X

Table 15b. Riparian vegetative zone width (Makai or Right Bank)

Locations	Optimal	Suboptimal	Marginal	Poor
Site 1			X	
Site 2				X
Site 3				X
Site 4				X
Site 5				X
Site 6				X
Site 7				X

III. Periphyton and Macroalgae Survey

Sample sites #1 and #2 contained a large number of rocks embedded in the sediment that had green tufts of algae growing on them. Samples were removed and taken to Vernon Sato for identification. The sample coral rock with the green tuft of algae was identified as *Cladophora socialis* with some *Lyngbya* sp. filaments attached at the base. *C. socialis* is considered to be circumtropical in its geographic distribution[2] and also can live in marine habitats. *Lyngbya* is a genus of cyanobacteria which are unicellular autotrophs that form the basis of the oceanic food chain. The genus is also known to tolerate saline environments. Apparently these two algal species are the main food source that is supporting the large tilapia population that inhabits this particular site. In addition to the two macroalgaes one diatom (*Achnanthes* sp.) was also observed under the microscope. This genus of diatoms are reported to be largely marine.

Sample of debris from Site #3 was quite devoid of anything living. There were a few very small diatom tests but they did not appear to be alive. There were a few flagellated and ciliated protozoans present but very few. This type of sample is usually characteristic of acidic waters containing decomposing vegetation. When left standing the water takes on a brown color (Figure 4) due to the build-up of tannins from the decomposition of leaf litter.

Figure 4. Water downstream of Site #3 emptying into Kailua Bay .

[2] http://eol.org/pages/967926/entries/38723861/overview

Since the area of the sampling was recently flushed with rain runoff it is suspected that the brown color would be flushed out leaving only sand and vegetative debris.

Along the bank of Sample Site #4 was 100% covered with a macrophyte that was identified as *Gracilaria tikvahiae*. This species occurs from cold temperate regions along the eastern Atlantic coast from Nova Scotia to warm subtropical regions around the east and west coasts of Florida and into the Caribbean[3] and is an introduction to Hawaiian waters. This red algal species is highly opportunistic and common in estuaries and bays, especially where nutrient loading leads to either seasonal or year-round eutrophication. It can be found in protected, quiescent bays, as well as in high energy coastline habitats. This species grows free or attached to rocks or other substrata, and can reach a height of 30 cm. *G. tikvahiae* grows to depths of approximately 10 m, but is most common at depths less than 1 m. The productivity of this species can be as high as any terrestrial crop on earth. Consequently, it has become the focus of several studies into its commercial value, primarily as a producer of hydrocolloids such as agar and carrageenan. It was the dominant biological commodity at Sample Sites #4, 5, and 7 covering 100% of the areas that made up the sample site. Such abundance clearly represents both a challenge and opportunity.

Figure 5. Photograph of *C. sericea* completely covering *G. tikvahiae* at Sample Site #6.

At Sample Site #6 a green filamentous algae was found covering 100% of the *G. tikvahiae* that was present. The green algae was keyed out to *Cladophora sericea*. This species is a branching green filamentous alga found on most reefs in Hawai‘i[4]. While this species is considered to be a native species it is also classified as invasive as it can spread and overgrow areas under the right conditions. *C. sericea* has demonstrated invasive characteristics in Hawai‘i, unlike the intertidal *C. vagabunda*. Approximately 10 years ago the alga became exceedingly abundant on leeward reefs in Maui and large blooms now occur seasonally. During the blooms, large masses of the alga drift in the water column, snagging on coral and rock outcroppings and smothering out the organisms beneath.

IV. Benthic Macroinvertebrate Survey

Rapid bioassessment using the benthic macroinvertebrate assemblage has been a popular means of assessing impacts among other state water resource agencies. During the current survey the Benthic Macroinverterbrate Field Data sheet was utilized to carry out an initial assessment of the Kaelepulu system. Copies of the raw data sheets are provided in the Appendices. A qualitative listing of the aquatic biota (four categories) that were surveyed at the various sites is summarized in Table 16. The one constant group with regard to abundance was the fish scoring a 3 (abundant) at all seven stations surveyed. In general, the macrophytes and macroinvertebrates

[3] http://www.sms.si.edu/irlspec/gracil_tikvah.htm#eutrophication
[4] http://hawaii.edu/reefalgae/invasive_algae/chloro/cladophora_sericea.htm

increased in the lake sections while the sites having a preponderance of filamentous algae was quite variable.

Table 16. Qualitative listing of aquatic biota: 0 = Absent/Not Observed, 1 = Rare, 2=common, 3=abundant, 4=dominant

Locations	Filamentous Algae	Macrophytes	Macro-invertebrates	Fish
Site 1	3	0	0	3
Site 2	4	0	0	3
Site 3	1	2	2	3
Site 4	1	4	3	3
Site 5	3	4	3	3
Site 6	4	3	2	3
Site 7	0	4	2	3

Field observations that recorded the presence of 11 taxonomic groupings of macroinvertebrates and their relative abundance is summarized in Table 17. It should be mentioned that the field data sheet includes 15 groups of insects and none of these groups had any representatives being caught or observed in the survey.

Table 17. Field observations of macrobenthos: 0=absent/not observed, 1 = Rare, 2=common, 3=abundant, 4=dominant

Location	Pori	Hydr	Plat	Turb	Hiru	Olig	Isop	Amph	Deca	Gast	Biva
Site 1	0	0	0	0	0	0	0	0	0	1	0
Site 2	0	0	0	0	0	0	0	0	0	1	0
Site 3	1	0	0	0	0	0	1	1	2	0	2
Site 4	0	0	0	0	0	0	0	3	2	0	2
Site 5	2	0	0	0	0	0	0	0	2	3	3
Site 6	0	0	0	0	0	0	0	1	0	3	2
Site 7	0	0	0	0	0	0	0	0	2	2	2

Pori=Porifera, Hydr=Hydrozoa, Plat=Platyhelminthes, Turb=Turbellaria, Hiru=Hirudinea, Olig=Oligochaeta, Isop=Isopoda, Amph=Amphipoda, Deca=Decapoda, Gast=Gatropoda, Biva=Bivalvia.

The number of distinct taxanomic groups represents the diversity of the macroinverterbrates within the survey and is a metric known as Taxa richness. This metric usually consists of species level identifications but can also be evaluated as designated groupings of taxa, often as higher taxonomic groups (i.e., genera, families, orders, class etc.) just as has been done for the assessment of macroinvertebrate assemblages in the current survey. The expected response to increasing perturbation varies depending on the metric but increasing diversity correlates with increasing health of the assemblage and suggests that niche space, habitat, and food source are adequate to support survival and propagation of many species. The predicted response of the number of taxa to a perturbation is for the Taxa richness metric to decrease. This can be illustrated graphically by displaying the number of taxa per sample location (Figure 6). Sample Site #3 was found to possess the highest taxa richness metric of all the sample sites. Sites #1 and #2 were observed to have the lowest values for the same metric. Both of these sites also possess the lowest dissolved oxygen levels as well as salinity clearly marking them as being impacted habitat. The lowered value in taxa richness at these two sites is consistent with a suitable metric that responds as predicted.

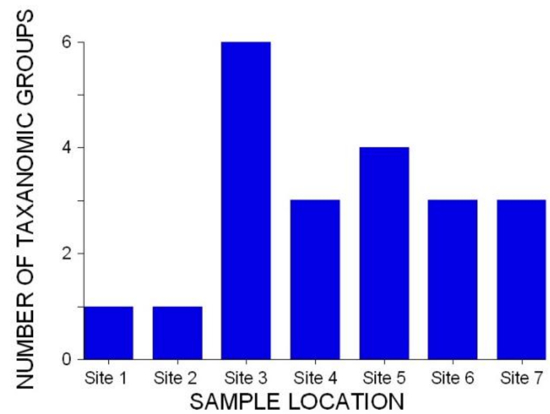

Figure 6. Variation in the number of taxanomic groups of macroinvertebrates at various sampling sites obtained during the current biological survey.

V. <u>Fish Survey</u>

Monitoring of the fish assemblage is an integral component of many water quality management programs, Field and data collections were conducted using three methods which were cast net, dip nets and visual identification. The latter became particularly important at Sites 5, 6 and 7 which were completely overgrown with macrophytes compromising the use of either nets to obtain specimens. However, data from the other assemblages indicates that the fish populations in the survey area are severely impacted and consist largely of three species as will be presented in the following sections.

<u>Metric 1. Total number of fish species.</u> A total of 13 fish species were collected or visually identified during the survey period. Based on discussions and observations made throughout the year there are clearly other species that are present that are not represented in this particular survey. However, to make the comparisons of the various sites requires that the data be standardized and only species collected or visually identified during the current survey are being used. Photographs of each of the species obtained make up the species list and is presented in the Appendix. A summary of the number of fish species among the various sample sites is presented in Figure 7. It is interesting to note that this particular metric of diversity mimics that observed for the macroinvertebrates where Sites #1 and #2 have the least

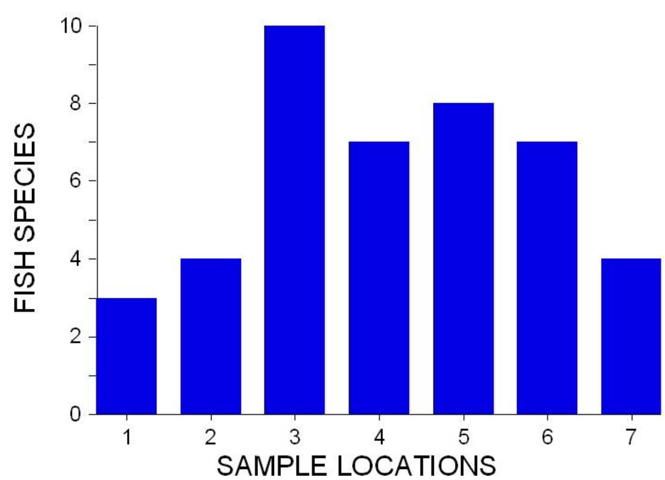

Figure 7. Total number of species found at each of the sample sites during the survey.

number of species and Site #3 has the most. The three fish species that were found at all of the sampling sites is presented in Figure 8. From top to bottom they are the mosquito fish (*Gambusia affinis*), mollies (*Poecillia* sp.) and the black chin tilapia (*Sarotherodon_melanotheron*). All three species share several characteristics and they are:

- Introduced species
- Euryhaline
- Omnivorous
- Highly tolerant to low dissolved oxygen levels
- Highly invasive.

The fish assemblage found in Site #2 only differs with the addition of one species commonly known in the aquarium trade as the red devil (*Amphilophus citrinellis*). Like the other three species it shares the same characteristics. The red devil, however, is largely restricted to the Hamakua canal and not seen in other locations of the study area. That the predominant fish species of the survey area are all introduced provides a clear indication that the fish assemblage in the study area has been severely compromised. Site #3, however, was found to possess 10 of the 13 species (Figure 7) recorded in the study area and indicates at least one area that has not been fully impacted.

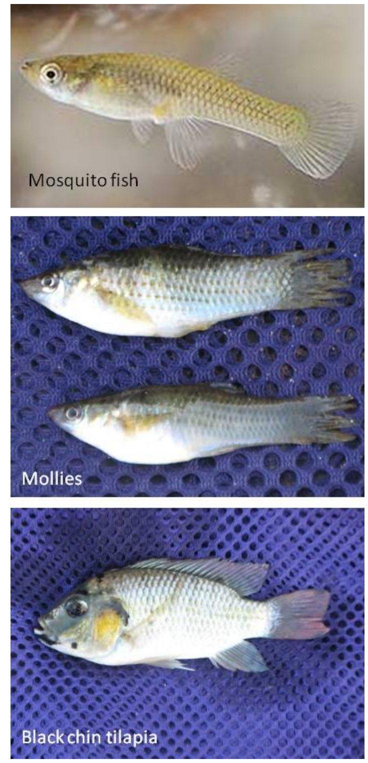

Figure 8. Three fish species found at all sample locations during the current survey.

Metric 2. Number and identity of intolerant species.

This metric distinguishes high and moderate quality sites using species that are intolerant of various chemical and physical perturbations. Intolerant species are typically the first species to disappear following a disturbance. All of the fish species collected or visually identified during the survey along with information about their tolerance and biology is summarized in Table 18. Using a combination of tolerances to both salinity and DO a rating of tolerant was established if the species was scored as moderate or above in both categories. If not a sensitive rating was assigned and using these criteria five species (*Arothron hispidus, Atherinomorus insularum, Saurida gracilis, Scarus dubius, Sphyraena barracuda*) were characterized as being sensitive.

A graphic summary of the percent composition of sensitive species among the various sample sites is provided in Figure 9. Sites #1, #2 and #7 were found to be devoid of sensitive species and indicates that these areas have been impacted.

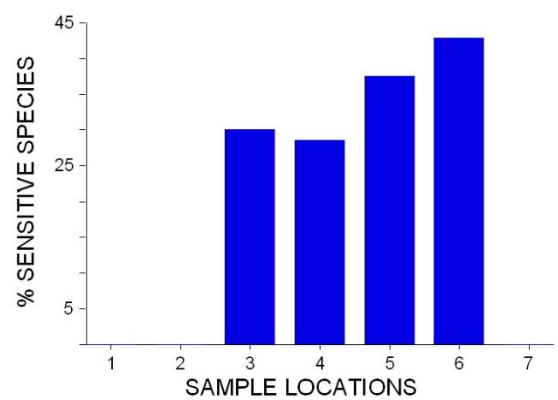

Figure 9. Percent composition of sensitive species among the various sampling sites.

However, it should be mentioned that the sampling done in site #4, #5, #6 and #7 were done visually due to the large amount of macroalgae that prevented the use of the throw net. In this case the sampling protocol may not have been as efficient. What is pleasantly surprising when using this metric is that the remaining areas do have a number of sensitive species and that would indicate that the overall quality of the study area may not be as dire as one might think.

Table 18. Summary of species collected or visually identified during the current survey.

Species (Scientific Name)	Distribution	Trophic Guild	Salinity tolerance	Dissolved Oxygen	Rating
Amphilophus citrinellis	Introduced	omnivore	moderate	high	tolerant
Arothron hispidus	Native	omnivore	moderate	moderate	sensitive
Atherinomorus insularum	Native	planktivore	moderate	low	sensitive
Chelon engeli	Introduced	omnivore	high	moderate	tolerant
Saurida gracilis	Native	carnivore	low	unknown	sensitive
Poecilia sp.	Introduced	omnivore	high	high	tolerant
Sarotherodon_melanotheron	Introduced	omnivore	high	high	tolerant
Kuhlia sandvicensis	Native	planktivore	high	moderate	tolerant
Gambusia affinis	Introduced	omnivore	high	high	tolerant
Scarus dubius	Native	herbivore	moderate	low	sensitive
Mugil cephalus	Native	herbivore	high	moderate	tolerant
Chanos chanos	Native	herbivore	high	moderate	tolerant
Sphyraena barracuda	Native	carnivore	moderate	low	sensitive

Metric 3. Proportion of individuals as omnivores

Omnivores are defined as species that consistently feed on substantial proportions of plant and animal material. The species that are omnivorous in the current survey were identified and are summarized in Table 18. The rationale for the use of this metric is that the percent of omnivores in the community increases as the physical and chemical habitat deteriorates. The percentage of omnivorous species that were found at each of the sampling sites is summarized in Figure 10. Only site #3 was found to have less than 100% of the species composition being omnivorous due to the presence of at least two carnivorous species (*S. gracilis* and *S. barracuda*). The high percentage of omnivores present in the majority of sampling sites indicates a substantial deterioration of the physical and chemical habitat in the study area.

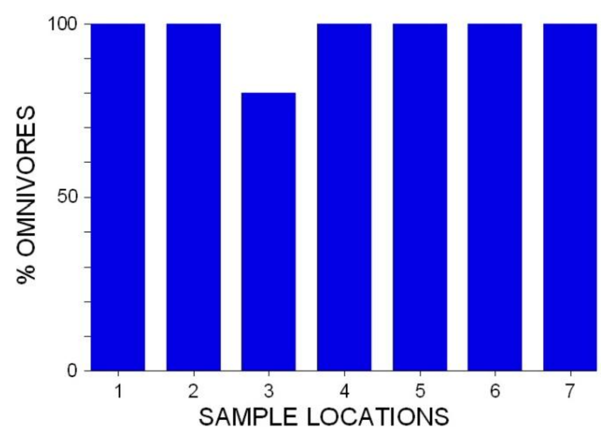

Figure 10. Distribution of omnivorous fish species among the various sampling sites in the current survey.

Metric 4. Proportion of individuals as top carnivores.

The top carnivore metric discriminates between systems with high and moderate integrity. Top carnivores are species that feed, as adults, predominantly on fish and other vertebrates. There were only two carnivores identified in the current survey and while others are present they were not captured. However, because all of the sampling was done within a specified time frame a comparison of the various sampling sites can be made and is presented in Figure 11. Interestingly this metric mimics that of the sensitive species as sites #1,#2 and #7 are devoid of carnivores. As mentioned previously the existence of a carnivore at site 7 is highly probably and may have not been sampled appropriately due the large amount of macroalgae present. None the less their presence in four of the seven sampling sites would indicate that there are areas of the study area that still remain of moderate integrity.

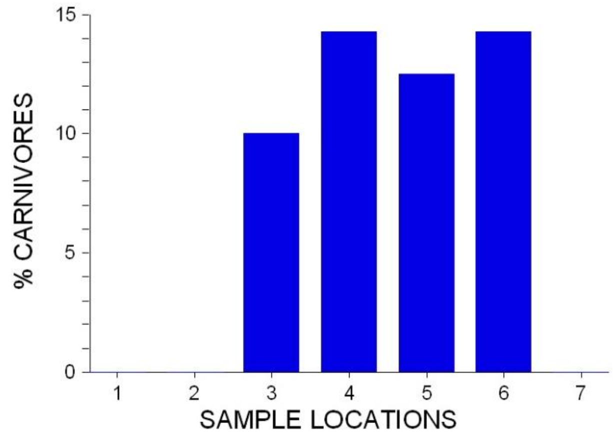

Figure 11. Summary of the percent composition of carnivorous fish species among the various sampling sites of the current survey.

Metric 5. Number of individuals in a sample.

This metric evaluates population abundance and varies with region and water body size. It is expressed as catch per unit effort, either by area, distance, or time sampled. Generally sites with lower integrity support fewer individuals, but in some nutrient poor regions, enrichment increases the number of individuals. For the current survey the catch per unit effort is in terms of individuals per unit area since the thrownet can be considered a quadrat. In this case the cast net is a quadrat that covers 154 ft^2. In addition the time spent to catch was limited to 30 minutes which proved to be sufficient to conduct three casts along the100 meter section of the sampling site. This would also include counting the number of individuals and scoring the species. Catch per unit effort would then be expressed in terms of unit area (ft^2) and per hour. Sites #4, #5, #6 and #7 presented problems with the use of the cast net because of the large amount of macroalgae on the bottom. So these areas were not included in the estimate of abundance. A summary of the results is presented in Table 19. The highest number of individuals (n=352) from a single cast was obtained at Site 1 and contributed to the high catch per unit effort values from that site. A similar situation was observed at site #2 and it should be noted that for these two sampling sites that although the catch per unit effort values are spectacularly high it must also be tempered in that the composition of the individuals obtained were consistently one species (i.e., *S. melanotheron*). All of the individuals captured at Site #1 were the black chin tilapia and of the 281 individuals captured at site #2 only two of them were the red devil species. All others were black chin tilapia. This was also the case with site #3 and although it yielded a total of 10 different species the majority in number (n=66) were the black chin tilapia. Caution is warranted about the use of this metric of abundance to indicate a “lower integrity” for supporting fish populations for the study area.

Table 19. Summary of catch per unit effort at various sample site locations.

Site Location	Number of casts	Total number caught	Average # of fish/ft^2	Range	# caught per hour
Site 1	3	519	1.7	1.1 – 2.3	1038
Site 2	3	281	0.6	0.4 – 0.8	562
Site 3	3	82	0.2	0.1 – 0.3	164

Metric 6. Proportion of individuals as introduced species.

This metric is an estimate of reproductive isolation or the suitability of the habitat for reproduction. Generally as environmental degradation increases the percent of introduced species also increases. Of the 13 species identified during the current survey five (38.5%) of them are introduced species. As indicated in the previous sections three of the introduced species (i.e., *S. melanotheron, G. affinis* and *Poecilia* sp) have become the predominate fishes in the entire study area. The composition of introduced species found at the various sampling sites could also be determined and the results of that analyses is summarized in Figure 12. As can be seen sites #1 and #2 are composed entirely of introduced species and clearly identifies these areas as impacted. This result is consistent with the water chemistry data (e.g., salinity and dissolved oxygen) and combined clearly indicates an impacted water body. Site #3 has the lowest composition of introduced species but this is largely based on the number of species rather than on biomass. From plain observation, it can easily be seen that if an estimate of biomass was obtained it would clearly indicate the predominance of introduced species in this area as well. The remaining sites can also be characterized as being predominantly (50% or more) made up of introduced species.

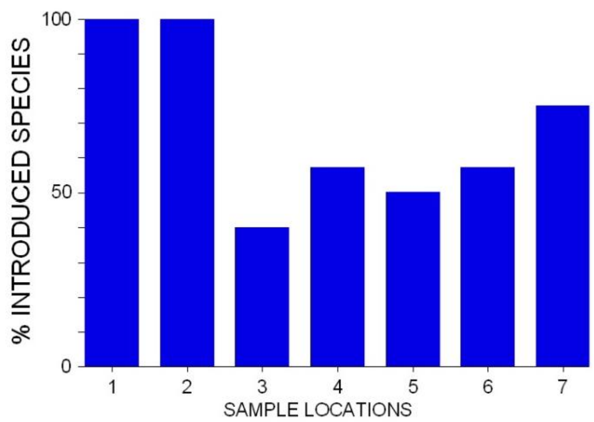

Figure 12. Summary of the percent composition of introduced species at the various sampling sites in the current survey.

Reference:

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling.1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.