A Biological and Habitat Assessment of Lower Lawai Stream, Kauai

Final Technical Report to The National Tropical Botanical Garden - June 2007

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Lower Lawai Stream, Feb 2007

EXECUTIVE SUMMARY

Located on the southern portion of Kauai, Lawai Valley is a drainage system for an elevated wetland (Kanaele Swamp) located in a bowl-shaped geologic feature below Mt. Kahili. Lawai Stream originates in the Lihue Koloa Forest Reserve in its headwater reaches, passes through low-density residential subdivisions and agricultural lands in its middle reaches before entering an increasingly incised lowland valley feature on its way to its deep estuary and Lawai Bay. This lowland segment of Lawai Stream is surrounded by agricultural lands which are elevated above the stream channel. Irrigation systems first constructed by McBryde Sugar Company in 1899, rely on groundwater resources which feed Lawai Stream; however, the long-term effect of these systems of ditches and reservoirs on Lawai Stream hydrology and ecology are not known.

Habitat and biological assessment studies initiated in Lawai Stream in May 2005 were conducted as one facet of a larger Project initiated by the National Tropical Botanical Garden to restore riparian areas adjacent to a reach of stream *mauka* of the estuary. The long-term objective of the restoration effort was to improve the "ecological health" of the estuary and lower segments of Lawai Stream in order to protect populations of native freshwater and marine aquatic species, turtle nesting activities on Lawai beach, and nearshore coral reefs from sedimentation and pollution. The restoration effort incorporates the planting of native riparian vegetation, appropriate for the region, to stabilize streambanks thereby reducing soil erosion and stream sedimentation. In addition, best management practices were initiated for the major agricultural road crossings of the stream. A long-term ecological monitoring program was also initiated to provide baseline data for evaluating the effects of conservation measures on the health of the stream, estuary, and nearshore environments.

The study design called for the establishment of two stream study sites within the riparian restoration area where a standardized stream assessment methodology (the Hawaii Stream Bioassessment Protocol - HSBP) was applied. The purpose of the HSBP is to evaluate the "health" or "biological integrity" of the stream as well as the condition of the habitat. Sites were sampled in Mar 2005 and Aug 2006. HSBP results averaged for the two sites sampled in the two years, rated both overall habitat condition and biotic integrity for the segment of lower Lawai Stream as "Poor" (60.5 $\pm$ 3.123 % and 60.9 $\pm$ 5.619 % of Reference, respectively). Stream habitat ratings were similar in study sites in annual surveys with the primary factors reducing habitat quality in both sites related to the presence of high sediment levels in the stream channel, chronic stream bank instability / erosion, and extreme variability in water levels / flow regimes. Despite the "Poor" habitat, overall biological integrity was determined to range from "Poor-to-Fair" (45.5 % to 70.9 % of Reference). Native aquatic species presence in this estuarine-influenced reach was found to be relatively robust with all expected native *'o'opu* and *'opae* species consistently present albeit not at abundance levels comparable to that found in high quality streams. Particularly notable during the study were improvements observed in the populations of *'o'opu-nopili* (*Sicyopterus stimpsoni*) which are highly "sensitive" to human-induced degradation. The dominant alien species collected in lower Lawai stream (by number and biomass) through electrofishing, was the alien Tahitian prawn (*Macrobrachium lar*). Of ecological concern was the presence of a large population of the alien cichlid, *Oreocromis mossambicus* (Mozambique mouthbrooder) in the estuarine reach and a growing population of the alien atyid shrimp, *Neocaridina denticulata sinensis* (grass shrimp), which appears to be gaining a foothold in lower Lawai Stream.

Compared to Oahu streams, Lower Lawai Stream is only moderately degraded in habitat and biological integrity; however, these are early signs of the chronic effects of urbanization on stream health. Residential and agricultural uses of lands surrounding Lawai Valley are the likely sources of soil erosion and stream flow alterations that are degrading the ecological integrity of Lawai's freshwater resources and should be further studied.

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PROJECT BACKGROUND

Lower Lawai Stream Riparian Restoration Project

Habitat and biological assessment studies initiated in Lawai Stream in May 2005 were conducted as one facet of a larger Project initiated by the National Tropical Botanical Garden (NTBG) to restore an approximately 1 km reach of lower Lawai Stream located on the south shore of Kaua`i, Hawaii (Figure 1). The long-term objective of the restoration effort was to improve the "ecological health" of the estuary and lower segments of Lawai Stream in order to protect populations of native freshwater and marine aquatic species, turtle nesting activities on Lawai beach, and nearshore coral reefs from sedimentation and pollution. The restoration effort incorporates the planting of native riparian vegetation, appropriate for the region, to stabilize streambanks thereby reducing soil erosion and stream sedimentation. In addition, best management practices (BMP's) were initiated for the major agricultural road crossings of the stream. A long-term ecological monitoring program was initiated to provide baseline data for evaluating the conservation treatments in terms of the health of the stream, estuary, and nearshore environments. Partners in this effort include the other landowners in the watershed (e.g., Kauai Coffee Company), State and Federal agencies, the Watershed Council, and scientists from the Hawaii Stream Research Center. Garden employees, interns, and volunteers were enlisted in the research and restoration activities. An educational component was introduced into the Project through the participation of K-12 and college groups as well as through the production of a film concerning these and other restoration activities on Kaua`i.

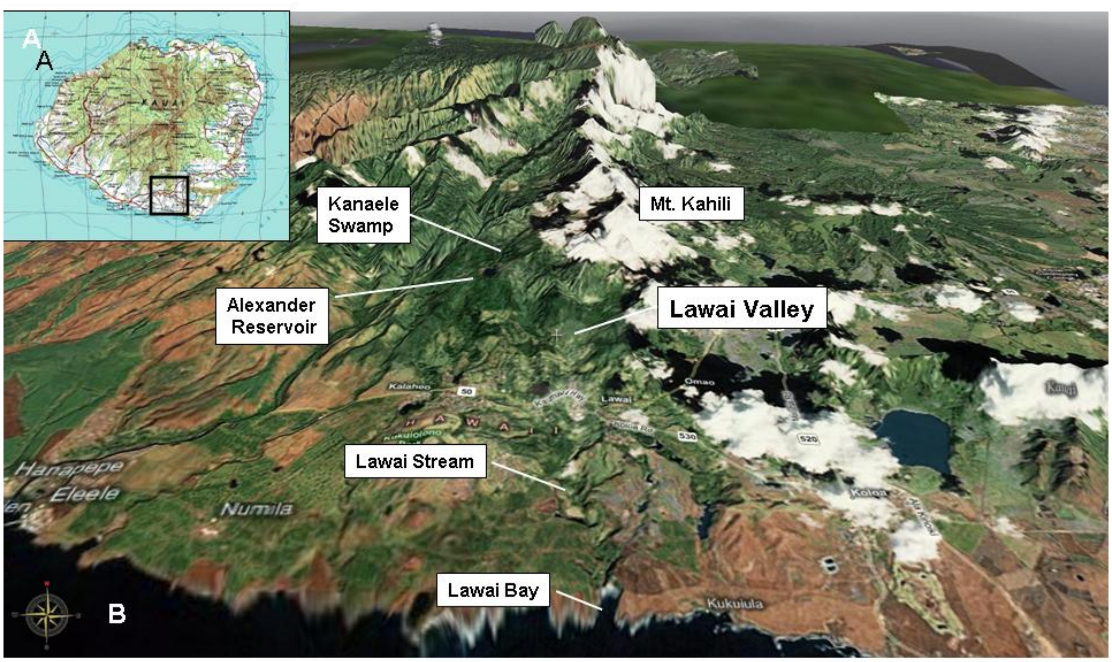

Figure 1. A. Project area on south Kauai. B. Landsat 7 image of Lawai Valley features.

Lawai Valley

Located on the southern portion of Kauai island, Lawai Valley is a drainage system for a bowl-shaped geologic feature about 4 km wide (~ 2.4 mile) below Mt. Kahili inside of which sits Kanaele Swamp (Fig 1). Lawai Valley is roughly 3400 hectares (~ 8405 acres) in total size with Lawai Stream descending from its headwaters at about 549 m elevation (1800 ft) to the ocean at Lawai Bay a straight line distance of about 8.5 km (~5.3 miles). Five unnamed tributaries drain Lawai's upper watershed joining its main channel by the time the stream reaches 182 m elevation (~ 600 ft). The stream originates in the Lihue Koloa Forest Reserve in its headwater reaches, passes through low-density residential subdivisions and agricultural lands in its middle reaches before entering an increasingly incised lowland valley feature 61 m (200 ft) deep in sections which begins about 1.4 km (0.87 mile) downstream of its intersection with Kaumualii Highway. This incised segment of the stream is surrounded by agricultural lands which are elevated above the stream channel. Lawai Stream is one of a relatively small group of Hawaii streams which supports a deep estuarine reach and associated wetland features before entering into the ocean at Lawai Bay (Fig. 1).

Agricultural operations of the McBryde Sugar Company from 1899 to its closing in the 1990's likely had a significant influence on the hydrology and physiognomy of Lawai Stream through sugarcane growing activities and its extensive system of diversions, ditches, and reservoirs in the region. Unlike other Kauai plantations, McBryde was more dependent upon groundwater in particular the Wahiawa watershed including the Kanaele Swamp (Wilcox 1996) which also is the source of Lawai Stream. To capture water from this groundwater resource, McBryde built Alexander Reservoir (Fig. 1) which was completed in 1932 after 4 years of construction and a major disaster when the dam broke under heavy rains on 26 March 1930 and took six lives (Wilcox 1996). The Alexander dam is the second-highest earthen dam in Hawaii holding a capacity of over 800 million gallons at about 488 m elevation (1600 ft) above Kalaheo town (Fig. 1). Much of the old McBryde irrigation system remains today with at least six reservoirs surrounding lower Lawai Stream; however, the cumulative impacts of water diversions, withdrawals, and inputs from this system on the hydrology and ecology of Lawai Stream is not know.

Hawaiian Cultural Background

Little written information about Lawai in pre-European contact Hawaii could be found in preparation for this study. Lawai was included in the southern *moku* of Kaua'i, one of 14 *ahupua'a* found from the island's south-eastern tip to the dry western shores of the Nāpali cliffs. One of Kauai's most southerly *ahupua'a*, it apparently included Nomilu Fishpond to the west and bordered on Waikomo Stream eastward to Koloa. According to Handy and Handy (1978), there were taro *lo'i* on flats above the sea and along Lawai Stream for a mile or more inland, and beyond this were small *lo'i* in the narrow lowland valley; however, there was no evidence of taro cultivation in the most mauka areas of Lawai Valley in the headwater reaches of Lawai Stream.

The most well documented feature of the Lawai *Ahupua'a* is *Nōmilu Fishpond*. This saltwater pond, located about 2.5 km (1.6 miles) west from Lawai Bay (Fig. 2), is situated inside an extinct *lua pele* (volcanic crater). In Hawaiian mythology, this was believed to be the first place on Kaua'i and location in the Hawaiian chain where Pele dug into the earth with her *ko'oko'o* (staff), seeking a suitable place to live. Wendell Bennett (Bishop

Musuem Bulletin 80, 1931, p. 116) gives an interesting account of Nōmilu: "The fish pond is a large, natural, salt water pond with no artificial work done to it. It is famous in Kaua'i history and every great chief who visited the island made a journey to it. On the sea side of the pond are salt pans partitioned off with stones, and at slightly different levels. The salt from these pans was famous. The inland part of the pond is overgrown with cactus and lantana. There are numerous walls here and several lines of stones that run into the water. A burial cave is reported in the cliffs above. Back of the modern gardens, running up the slope, are taro terraces faced with stone, and whether they were irrigated or not is still a question, since no fresh water can be seen".

Previous Scientific Studies

Lawai Stream is identified in the Hawaii Stream Assessment (HSA 1990) (HSA Code 2-3-04) which ranks it as 'Moderate' for aquatic resources (only 'Outstanding' was a higher ranking) with three fish and invertebrates in 'Native Species Group Two' and two in 'Introduced Species Group One' observed during a previous survey conducted in 1978. Of the five *'o'opu* species native to Hawaiian streams, only *Awaous guamensis* (*'o'opu-nakea*) and *Sicyopterus stimpsoni* (*'o'opu-nopili*) were reported in Lawai Stream in the 1978 survey; however, no details on the survey methods or metadata were provided. For riparian resources, the HSA (1990) indicates the presence of a palustrine wetland with twenty percent of the overall watershed remaining in native forest. In the terrestrial biota of Lawai Valley were listed *hau* (*Hibiscus tiliaceus*), California grass (*Brachiaria mutica*), and feral pigs as detrimental plants and animals. No 'Threatened and Endangered' bird species were noted in the report for Lawai Stream.

Timbol and Maciolek (1978) in their statewide inventory of streams, did not list any named tributaries of Lawai Stream rating it a Category II 'Limited Consumptive' (i.e. 'Moderate to high quality water or natural values: controlled use to prevent excessive modification') indicating relatively good biophysical conditions. The stream channel was determined to be channelized or altered; stream continuously flowing to the ocean; impacted by ten road crossings and three diversions withdrawing water from the stream (Timbol and Maciolek 1978).

A U.S. Geological Survey stream flow gage was operated on lower Lawai Stream at ~ 11 m elevation (37 ft) from Jul 1963 to Oct 1972 (http://water.usgs.gov/) to monitor surface water volume. Mean flow in Lawai Stream at this elevation for this eleven year period was calculated as 7.6 $\pm$ 1.145 cubic feet per second (cfs). Minimum, maximum, and median stream flow during this period was 3.07 cfs, 15.5 cfs, and 7.03 cfs, respectively.

Scope of Work and Objectives for the Lawai Stream Riparian Restoration Project

In Lawai Stream, our study design called for the establishment of two stream study sites located within the riparian restoration area where a standardized stream assessment methodology (the Hawaii Stream Bioassessment Protocol - HSBP) (Kido 2002a) would be applied. The purpose of the HSBP is to evaluate the "health" or "biological integrity" of the stream as well as the condition of the habitat. The concept of "integrity" is a holistic one and incorporates the idea that comparisons are made using the "functions and components of whole natural systems" (Miller and Rees, 2000) as examples of robust ecological health. Ecosystem health presumably degrades as human influence escalates. The Hawai'i Stream Index of Biological Integrity (HS-IBI) (Kido 2002a) incorporates these ideas and was developed to evaluate the health (as measured by the status of biotic integrity) of Hawaiian stream ecosystems.

In each study site the objectives of the assessment were to:

1. Develop a species list of fish, macroinvertebrates, and macroalgae inhabiting the stream system;
2. Evaluate and compare condition and species composition of the riparian area adjacent to the study stream reach;
3. Assess stream habitat quality in the study reach;
4. Evaluate the "biotic integrity" of the stream environment as compared to Hawaiian stream "reference" standards;

Only habitat and biological integrity results are provided in this Interim Report.

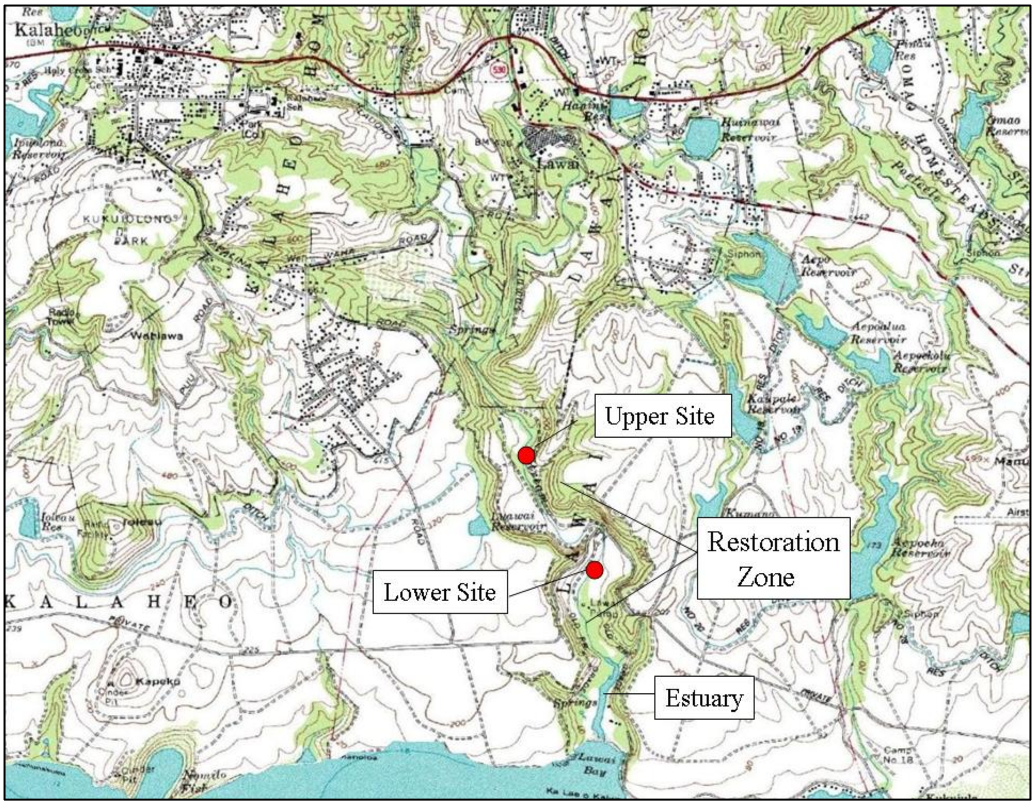

Figure 2. Location of bioassessment study sites in lower Lawai Stream.

MATERIALS AND METHODS

Two study sites were chosen within the restoration zone of lower Lawai Stream at 11 m (36 ft) elevation (Lower Site) and 37 m (121 ft) elevation (Upper Site) (Fig. 2). Lower and Upper Sites were both 120 m (394 ft) in length following a standard requirement that sites be a minimum of twenty times mean stream width (Kido 2002a). At each of the selected sites, habitat condition and biological integrity were measured using the Hawaii Stream Bioassessment Protocol (HSBP) (Kido 2002a) in March 2005 and subsequently in August 2006. The HSBP utilizes sampling protocols and metrics for two integrated indices which evaluate: 1) the "biotic integrity" of the stream location (using the Hawaii Stream Index of Biotic Integrity (HS-IBI) and; 2) the condition of the supporting habitat for for aquatic organisms. According to HSBP protocol (Kido 2002a), study site length was standardized to 20 times mean stream width (100 m minimum) and physiognomy mapped for incremental length / sinuosity / slope and stream habitat characteristics. In addition, riparian habitat on each bank (stream edge to ~10 m inland) was evaluated for physical condition, species composition, and canopy closure. Stream flow in each study site was also measured using a Swoffer flow meter and top-setting wading rod.

For sampling the fish population in the stream, the HSBP will be modified (because of the degraded stream conditions) to use a backpack electroshocker for collecting. Electrofishing only temporarily stuns the fish which are subsequently collected and examined for species / size / condition. In order to evaluate the levels of primary / secondary productivity and standing crops of algae / mosses / invertebrates, instream plant and invertebrate biomass densities and species composition were measured in at least two locations within each site using a Surber net and rock removal method described in Kido (1997a). The material collected was stored in the field in phosphate buffered formalin and processed / analyzed in the laboratory as described in Kido (1997a).

The Hawaiʻi Stream Bioassessment Protocol 3.01 (HSBP)

Evaluations of stream habitat and biological quality at study sites on a scale from "Excellent" to "Very Poor" provide valuable information useful in evaluating environmental impact or change in ecological condition over time. The Hawaiʻi Stream Bioassessment Protocol (Kido 2002a) was developed specifically for this purpose and used in this study. The HSBP utilizes a standardized "multimetric" approach to evaluate both habitat condition and biological quality of the study stream reach. Protocols used in the study involve underwater visual observation or electrofishing collections to score eleven "metrics" (or measures) that provide ecological insight from the individual, population, and community levels of ecological organization of the native macrofauna (Table 1,2, 3). The raw data is then used to calculate the Hawaii Stream Index of Biotic Integrity (HS-IBI) which rates biological quality in comparison to reference Hawaiian stream conditions on a scale from 0 % (< 40 % is impaired) to 100 % (Excellent)(Table 1,2,3). The HSBP also evaluates stream habitat quality for various characteristics which support native aquatic organisms as well as riparian habitat for their ability to buffer the stream environment from land-based anthropogenic degradation (Table 4). Ten physical habitat metrics are scored in the protocol and rated according to a percentage scale (i.e. 0 % to 100 %) similar to that of the HS-IBI which rates habitat quality as compared to reference from "Excellent to Poor" (Table 4). Readers interested in more specific details of HSBP procedures are referred to an online version of the manual found at the Department of Health EPO website at www.hawaii.gov/doh/eh/epo/wqrev.htm.

Table 1. Native Hawaiian stream macrofaunal assemblage.

Taxa	Hawaiian Name	Status
Teleostei; Perciformes; Gobioidei		
Eleotridae - *Eleotris sandwicensis*	***ʻoʻopu-ʻakupa***	**endemic**
Gobiidae - *Awaous guamensis*	***ʻoʻopu-nākea***	**indigenous**
Lentipes concolor	***ʻoʻopu-alamoʼo***	**endemic**
Sicyopterous stimpsoni	***ʻoʻopu-nōpili***	**endemic**
Stenogobius hawaiiensis	***ʻoʻopu-naniha***	**endemic**
Arthropoda; Crustacea; Decapoda;		
Atyidae - *Atyoida bisulcata*	***ʻōpae-kalaʼole***	**endemic**
Palaemonidae - *Macrobrachium grandimanus*	***ʻōpae-ʻoehaʼa***	**endemic**
Mollusca; Gastropoda; Neritidae		
Neritina granosa	***hīhīwai***	**endemic**
Theodoxus vespertinus	***hapawai***	**endemic**
Theodoxus cariosus	***hapawai***	**endemic**

Table 2. HS-IBI ratings, integrity classes, and class attributes.

HS-IBI Score as % of Reference	Integrity Class	Attributes
90 - 100 %	**Excellent**	**Comparable to reference conditions with minimal human disturbance; all expected native macrofauna present with alien *M.lar* either absent or in very low numbers; robust *‘o‘opu* population meeting density and size-class expectations including those for sensitive *‘o‘opu* species (i.e. *‘o‘opu-nōpili* and/or *‘o‘opu-alamo’o*).**
79 - 89 %	**Good**	**All expected native macrofauna present; Alien *M. lar* present but in low proportionate abundance (< 10 %); total *‘o‘opu* populaion densites generally attained but sensitive *‘o‘opu* densities and/or size classes may be somewhat below expectations.**
69 - 78 %	**Fair**	**Most expected native macrofaunal species present; Alien *M. lar* present in greater proportionate abundance (> 10 %); total *‘o‘opu* population and sensitive species densities / size classes below expectations.**
59 - 68 %	**Poor**	**Few expected native macrofaunal species present; Alien *M. lar* as or more abundant than native species but other alien species absent or rare; total *‘o‘opu* population and sensitive species densities / size classes well below expectations.**
40 - 58 %	**Very Poor**	**Only one or two expected native macrofaunal species present and if present in very low abundance; Alien aquatic species dominate the community and may include tolerant fish species (e.g. Poeciliidae).**
< 39 %	**Impaired**	**Native aquatic macrofaunal species absent; Only alien species present including *M. lar* and tolerant fish species.**

Table 3. Biotic metrics and scoring used in the Hawaiian stream bioassessment.

	SCORING CRITERIA		
METRIC	**pts 5**	**3**	**1**
1a. Number of native amphidromous macrofauna (S_{NAM}) - High/Moderate Slope Mid Reach	4 - 3	2 - 1	0
1b. Number of native amphidromous macrofauna (S_{NAM}) - Low Slope Terminal Reach	6 - 5	4 - 2	1 - 0
2. Percent Contribution Native Taxa (PNT)	100% - 75%	74% - 50 %	≥ 49 %
3. Percent Sensitive Native Fish (SNF)[1]	≤ 50%	49% - 20 %	≥ 19 %
4. Sensitive Native Fish Density (fish sq m^{-1})[2]	≤ 0.46	0.45 - 0.20	≥ 0.19
5. Sensitive Native Fish Size (% ≥ 6.0 cm)[3]	≤ 50%	49% - 25 %	≥ 24 %
6. *Awaous guamensis* Size (% ≥ 8.0 cm)[3]	≤ 50%	49% - 25 %	≥ 24 %
7. Total Native Fish Density (fish sq m^{-1})	≤ 0.75	0.74 - 0.36	≥ 0.35
8. Community Weighted Average (CWA)	1.0 - 4.0	4.1 - 9.0	9.1 - 10
9. Number of Alien Taxa (NAT)	0 - 1	2 - 3	>3
10. Percent Tolerant Alien Fish	0%	1 - 4%	≥ 5%
11. Percent Diseased / Parasitized Fish	≥ 1 %	2 % - 10 %	≤ 11 %
Maximum Possible Points = 55			

[1] Sensitive species are *‘o‘opu-alamo’o* and *‘o‘opu- nōpili*; total no. individuals / total no. fish only
[2] Either *‘o‘opu-alamo’o* or *‘o‘opu-nōpili* (whichever is in highest density) but not both.
[3] Excluding post-larval size-classes (≤ 3.0 cm TL).

Table 4. Habitat metrics for the HSBP (*FPOM=fine particulate organic matter; CPOM=coarse particulate organic matter).

Metric	Optimal	Suboptimal	Marginal	Poor
1.Habitat Availability	≥ 80% of eleven possible habitat types present for slope gradient type (low, med, high)	51% - 79% of eleven possible habitat types present	26% - 30% of eleven possible habitat types present	≤ 25% of eleven possible habitat types present
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Substrate Embeddedness	Gravel, cobble, and boulder particles 0% - 10 % surrounded by fine sediment	Gravel, cobble, and boulder particles 11% - 25 % surrounded by fine sediment	Gravel, cobble, and boulder particles 26% - 74 % surrounded by fine sediment	Gravel, cobble, and boulder particles ≥ 75 % surrounded by fine sediment
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. FPOM*/CPOM* Characterization	FPOM / CPOM localized covering ≤10% of sq m quadrant	FPOM / CPOM obvious covering 11%-25% of sq m quadrant	FPOM / CPOM widespread covering 26%-50% of sq m quadrant	FPOM / CPOM dominant covering ≥51% of sq m quadrant
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Velocity-Depth Combinations	≥ 80% of seven possible flow regimes present for slope gradient type (low, med, high)	51% - 79% of seven possible flow regimes present	26% - 30% of seven possible flow regimes present	≤ 25% of seven possible flow regimes present
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Status	Ratio of stream width to bank-full width ≥ 80 %	Ratio of stream width to bank-full width 79% - 65%	Ratio of stream width to bank-full width 64% - 50%	Ration of stream width to bank-full width ≤ 49%
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
6. Channel Alteration	≤ 8 % of channel altered	10% – 23% of channel altered	24% - 44% of channel altered	≥ 45% of channel altered
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Bank Stability	≤ 8 % of stream bank unstable	10% – 23% of bank unstable	24% - 44% of bank unstable	≥ 45% of bank unstable
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Riparian Vegetation Zone Width	≥ 80% of riparian zone covered by trees/shrubs	51% - 79% of riparian zone covered by trees/shrubs	26% - 30% of riparian zone covered by trees/shrubs	≤ 25% of riparian zone covered by trees/shrubs
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
9. Percent Riparian Understory Coverage	≥ 80% of riparian zone covered by understory plants	51% - 79% of riparian zone covered by understory plants	26% - 30% of riparian zone covered by understory plants	≤ 25% of riparian zone covered by understory plants
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
10. Cobble / Boulder vs. Soil Presence	Boulder/Cobble substrate dominant feature; 0% - 10% of bottom affected by soil.	Boulder/Cobble substrate common feature;11% - 25 % of bottom affected by soil	Boulder /Cobble substrate margi-nal feature; 27%-50% of bottom af-fected by soil.	Boulder/Cobble substrate rare feature; > 51 % of bottom affected by soil deposition.
Points	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

RESULTS AND DISCUSSION
HABITAT AND BIOLOGICAL ASSESSMENT

In this ongoing study of lower Lawai Stream, two standard HSBP (Kido 2002a) bioassessment sites were established at Upper and Lower locations along the stream continuum at 11 m (36 ft) and 37 m (121 ft) elevation, respectively (Fig. 2). Surveys were conducted to collect baseline data on the status of stream habitat and biological condition so as to evaluate the effects of a riparian restoration project planned for this segment of lower Lawai Stream. Based upon HSBP data averaged for the two study sites (Mar 2005 / Aug 2006), both overall habitat condition and biotic integrity for the segment of lower Lawai Stream were rated "Poor" (60.5 $\pm$ 3.123 % and 60.9 $\pm$ 5.619 % of Reference, respectively) (Fig. 3).

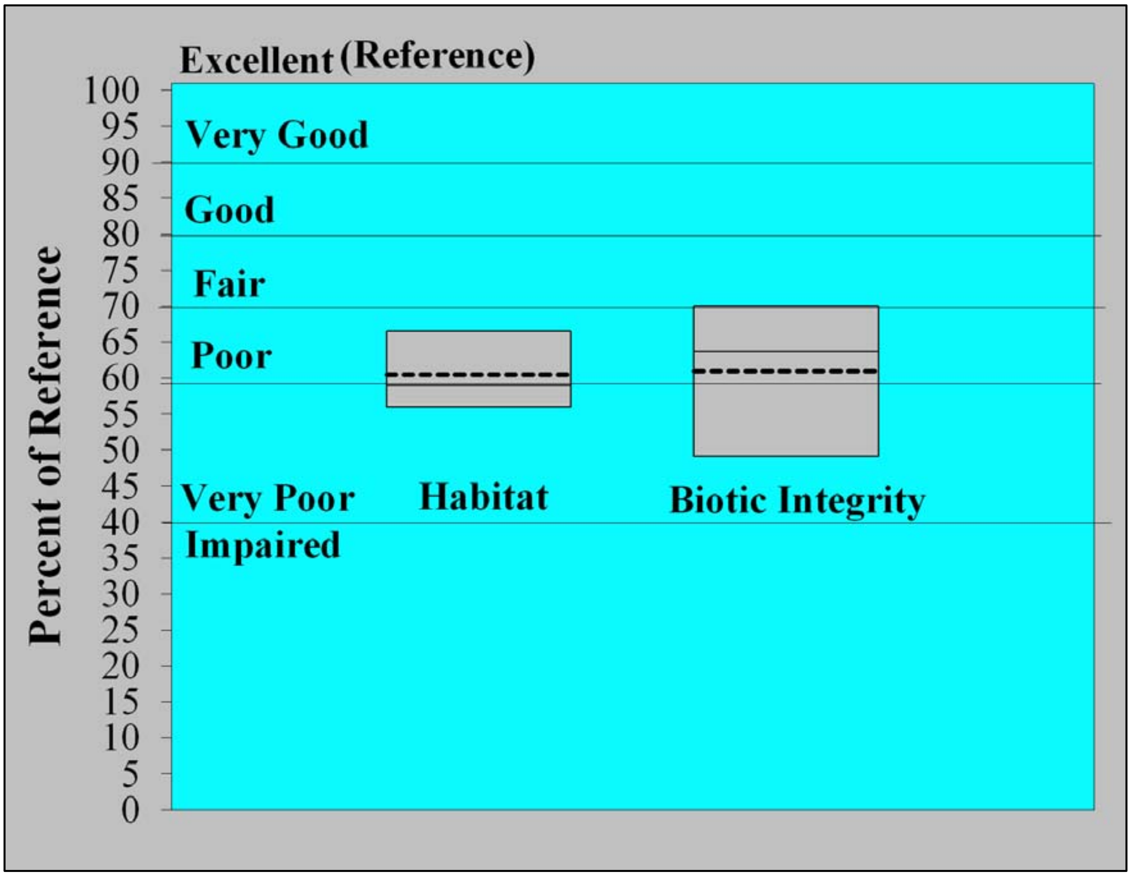

Figure 3. Box plots of averaged Habitat and Biotic Integrity ratings (by the HSBP) of lower Lawai Stream sites sampled in Mar 05 and Aug 06 (upper and lower lines of boxes indicate 90^{th} and 10^{th} percentiles respectively; dotted line inside box is the mean).

HSBP Habitat Assessments

Stream habitat ratings were similar in Lower and Upper sites ("Poor") in the Mar 2005 and Aug 2006 surveys (Table 5). The primary factors reducing habitat quality in both sites were related to the presence of high sediment levels in the stream channel, chronic stream bank instability / erosion, and extreme variability in water levels / flow regimes (Table 5). This low elevation reach of Lawai Stream is extremely susceptible to "upstream' impacts from sediment / storm water runoff originating in residential areas where extremely high sediment levels / unstable bank conditions were observed (MKido, unpublished data) as well as from surrounding agricultural lands primarily planted in coffee. Old sugarcane roads intersecting lower Lawai Stream are a likely a significant source of chronic sediment input into the lower reach during extended periods of rain. Water levels and flow status were also highly variable within- and among-sites and sample years (Table 5); however, it was not clear if this high variability was due to the effects of agricultural irrigation in the region or surface water runoff from surrounding residential areas or both.

Table 5. Scores for habitat metrics obtained from HSBP application in lower Lawai Stream sites.

Stream	LOWER SITE		UPPER SITE	
HSBP METRIC % of reference	Mar 2005	Aug 2006	Mar 2005	Aug 2006
1. Habitat Availability	92.00	92.00	100	100
2. Embeddedness	78.00	76.25	82.50	70.0
3. FPOM / CPOM Characterization	30.00	30.00	80.00	20.0
4. Velocity-Depth Combinations	93.80	93.75	93.00	43.75
5. Channel Status	71.25	43.75	65.00	85.00
6. Channel Alteration	0	0	0	0
7. Bank Stability	43.75	43.75	75.60	81.25
8. Riparian Zone Width	10.00	10.00	75.00	75.00
9. Riparian Understory	10.00	10.00	37.50	37.50
10. Boulder Cobble vs. Soil Presence	90.00	73.00	87.50	75.00
Total Points (Max = 200 pts)	118	112	128	133
Habitat Score (% of Reference)	59.00	56.00	64.00	66.50

The Biological Integrity of Lower Lawai Stream

Despite the “Poor” stream habitat ratings determined by the HSBP, overall biological integrity in lower Lawai Stream was determined to range from “Poor-to-Fair” (45.5 % to 70.9 % of Reference) in sites over the study period (Table 6). Native aquatic species presence in this estuarine-influenced reach was determined to be relatively robust with all expected native amphidromous fish and macroinvertebrates consistently present (at least in the Lower Site nearer the estuary) (Table 6). While abundance levels of native *‘o’opu* and *‘opae* populations were not comparable to that found in high quality streams, species were at least always present in Lawai Stream which is not the case with severely degraded streams on Oahu island (e.g. Kido 2000c, 2004, 2005). Particularly notable in the study period were improvements observed in the populations of *‘o’opu-nopili* (*Sicyopterus stimpsoni*) (Metric 2 – Table 6) which are highly “sensitive” to human-induced degradation (Kido 2002a). It is unclear why this marked increase in *‘o’opu-nopili* populations occurred. However, major flooding occurring during the study period may have played a role by scouring out the stream channel thereby removing debris and deposited sediment (at least temporarily) thereby improving conditions for better growth of algal food sources (Kido 1997a).

The dominant alien species collected in lower Lawai stream (by number and biomass) through electrofishing, was the alien Tahitian prawn (*Macrobrachium lar*) which is ubiquitous in streams throughout Hawaii because of its amphidromous life history. Also of ecological concern is the presence of large populations of the alien cichlid, *Oreocromis mossambicus* (Mozambique mouthbrooder), which are common in the estuary and observed (but not collected) in the Lower Site (Table 7). This African cichlid is extremely omnivorous, tolerant to degraded stream conditions and thus a significant detriment to native aquatic species populations but very difficult to eradicate.

Table 6. Scores for HS-IBI metrics obtained from HSBP application in lower Lawai Stream.

HSBP METRIC	HS-IBI Score: Lower Site Mar 05	Lower Site Aug 06	Upper Site Mar 05	Upper Site Aug 06
1. Number of native amphidromous macrofauna (S_{NAM})	5	6	4	2
2. Percent Contribution Native Taxa (PNT)	38.3%	41.1%	67.9%	50.0%
3. Percent Sensitive Native Fish (SNF)[1]	> 1 %	22.7%	2.8%	38.0%
4. Sensitive Native Fish Density (fish sq m^{-1})[2]	> 0.19	< 0.2	> 0.19	< 0.2
5. Sensitive Native Fish Size (% $\geq$ 6.0 cm)[3]	> 20 %	20 %	> 20 %	< 50%
6. *Awaous guamensis* Size (% $\geq$ 8.0 cm)[3]	< 50%	< 50%	< 50%	< 50%
7. Total Native Fish Density (fish sq m^{-1})	$\geq$ 0.35	< 0.36	< 0.36	< 0.36
8. Community Weighted Average (CWA)	7.2	13.0	6.2	6.4
9. Number of Alien Taxa (NAT)	4	3	2	2
10. Percent Tolerant Alien Fish	2.8 %	4.3 %	0%	0.8%
11. Percent Diseased/Parasitized Fish	0%	0%	0%	0%
Maximum Possible Points = 55 Total Points	25	37	33	39
HS-IBI Score (% of Reference)	45.5 %	67.3 %	60.0 %	70.9 %

[1] Sensitive species are *'o'opu-alamo'o* and *'o'opi- nopili*; total no. individuals / total no. fish only
[2] Either *'o'opu-alamo'o* or *'o'opu-nopili* (whichever is in highest density) but not both.
[3] Excluding post-larval size-classes ($\leq$ 3.0 cm TL).

Table 7. Species list and distribution of fish and macroinvertebrates in lower Lawai Stream study sites as determined by electrofishing (**X** indicates species presence, **N** indicates species not collected, ***** indicates native species, [1] indicates species observed but not collected).

Taxa	Lower Site Mar 05	Lower Site Aug 06	Upper Site Mar 05	Upper Site Aug 06
Teleostei: Perciformes: Gobioidei				
Eleotridae - *Eleotris sandwicensis**	X	X	X	X
Gobiidae - *Awaous guamensis**	X	X	X	X
*Sicyopterous stimpsoni**	X	X	X	X
*Stenogobius hawaiiensis**	X	X	N	N
Kuhliidae – *Kuhlia sandvicensis**	X	X	N	N
Cyprinodontiformes: Cyprinodontoidei				
Poeciliidae – *Gambusia affinis*	X	X	N	X
Xiphophorus helleri	N	N	N	X
Percoidea; Cichlidae				
Oreochromis mossambicus	X[1]	X[1]	N	N
Ostariophysis: Siluriformes: Clariidae				
Clarias fuscus	X	N	X	N
Arthropoda; Crustacea; Decapoda;				
Neocaridina denticulata sinensis	X	N	N	N
Palaenonidae – *Macrobrachium lar*	X	X	X	X
*Macrobrachium grandimanus**	X	N	X	N

A small population of the alien atyid shrimp, *Neocaridina denticulata sinensis* (grass shrimp) appears to be gaining a foothold in the lower reach of Lawai Stream (Table 7). This relatively recent introduction into Hawai'i has apparently become very common in O'ahu streams (e.g. Kido 2000c, 2004, 2005) and has essentially replaced the native shrimp (*'ōpae-kala'ole- Atyioida bisulcata*) from its preferred habitat in the middle-to-upper reaches of streams. Unlike native *A. bisulcata*, alien *N. denticulata sinenis* can reach very high densities anywhere along stream continua from mouth-to-headwaters and thus is extremely invasive and becoming a widely distributed pest species in streams around the state.

SUMMARY AND CONCLUSIONS

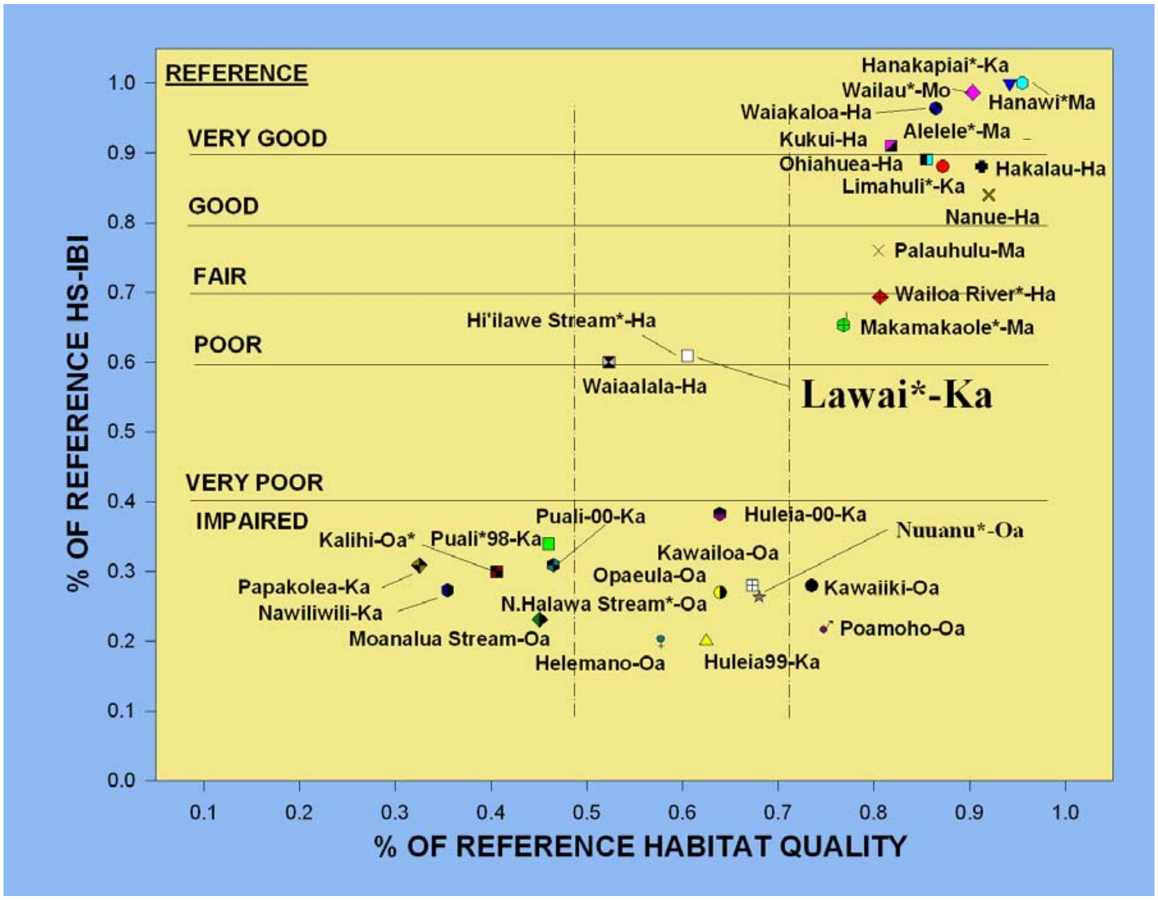

Figure 4. Statewide comparisons of stream biotic integrity (HS-IBI) and condition of supporting habitat in lower Lawai Stream (Kauai) sites sampled in Mar 05 / Aug 06 (*averaged values in streams that have been sampled at multiple elevations and/or times, Ka= Kaua'i, Oa= O'ahu, Ma= Maui, Mo= Moloka'i, Ha= Hawai'i).

Compared to other streams systems across the state, lower Lawai Stream is only moderately degraded in habitat and biotic integrity by the direct and indirect effects of urbanization (Fig. 4). Judging from the results of this study, it is still able to support relatively stable populations of native *'o'opu* and *'opae* populations although not at abundance levels comparable to better quality streams. The improvement in populations of the native stream herbivore, *'o'opu-nopili*, is a hopeful sign that some significant recovery of habitat and biotic integrity in Lawai Stream is possible if degradative influences occurring in its *mauka* watershed region can be identified and controlled in the long-term.

Although the upper watershed and headwater reaches of Lawai Stream were not sampled in this study, these areas appear to be well-forested and presumably stream channels and riparian zones are in relatively natural condition. The primary problem areas in Lawai Valley are in residential areas adjacent to the middle-lower reaches of stream where major rehabilitation of riparian zones and stream banks are required to reduce chronic soil erosion dumping sediment into the stream channel. Tilled land in agricultural areas in former McBryde sugarcane lands surrounding the lower reaches of Lawai Stream are likely also susceptible to soil erosion which conveys soil to the stream via run-off from old cane-haul roads during bouts of heavy rainfall. In addition, the natural hydrology and fluvial geomorphology of lower Lawai Stream has been modified by ditches, diversion, and reservoir systems since McBryde Sugar Company began operations in 1899. Much of this open irrigation system persists today over 100 years later; however, information on their present condition and impacts on Lawai Stream is not available. Thus, an inventory and assessment of the condition and hydrology of ditches and reservoirs in Lawai Valley is long overdue.

Lower Lawai Stream is starting to show the chronic effects of urbanization which originate with large-scale modifications of the landscape over time and the concentration of large numbers of people into relatively small spatial areas. Once vegetated areas are cleared for development, landscape modifications in urban areas in terms of degradation to stream ecosystems, generally relate to physical modifications of the stream channel (e.g. flood control projects, stormwater runoff, bank hardening, etc.) and / or anthropogenic activities (e.g. point/nonpoint source pollution, alien species introductions, etc.). A common pattern observed on Oahu are stream systems that flow from mountain-to-sea along gradients of intensifying urbanization and are impacted by increasing levels of habitat degradation and urbanization. Biological integrity along these gradients eventually become "Impaired" by the cumulative negative impacts of human activity to the point where native aquatic animals are extirpated from their natural ranges and replaced by alien aquatic species. Recent studies have shown that even relatively natural forested watershed areas in the headwaters of streams, continuous flow to the ocean, and lack of major water diversions, appear to be insufficient to counter the degradative effects of urbanization (Kido 2004, 2005). If streams are the surface reflection of groundwater integrity and abundance, then there is cause for concern about the long-term health and viability of drinking water sources in highly urbanized areas. As human populations in and around Lawai Valley continue to expand, the integrity, health, and sustainability of Lawai's ground- and surface-water resources will become increasingly serious issues of concern.

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