VOL. 2

Proposed Lease (Water Lease) for the Nāhiku, Ke‘anae, Honomanū, and Huelo License Areas

Draft Environmental Impact Statement

September 2019

Prepared For

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APPENDIX A:

Assessment of the Environmental Impact of Stream Diversions on 33 East Maui Streams using the Hawaiian Stream Habitat Evaulation Procedure (HSHEP) Model

Trutta Environmental Solutions, LLC

Assessment of the Environmental Impact of Stream Diversions on 33 East Maui Streams using the Hawaiian Stream Habitat Evaluation Procedure (HSHEP) Model

June 8, 2019

Prepared for:

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TRUTTA ENVIRONMENTAL SOLUTIONS, LLC

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ABSTRACT

The East Maui Irrigation (EMI) Aqueduct System supplies water to some 30,000 acres of agricultural land in Central Maui and serves more than 30,000 Upcountry Maui residents and farmers. The EMI Aqueduct System was built between 1876 and 1923 to collect and deliver surface water to sugarcane fields in Central Maui (CWRM D&O 2018). The EMI Aqueduct System has diverted water in its current configuration for nearly 100 years and baseline environmental condition studies (including the distribution and habitat of native stream animals) prior to its construction do not exist. To better understand the impact of the surface water diversion on native stream animals and their habitats, Trutta Environmental Solutions, LLC. (TRUTTA) was contracted to develop a Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model to assess impacts on 33 streams[1] associated with a Water Lease receiving the amount of streamflow diversion allowed under the 2018 Interim Instream Flow Standard (IIFS)

The HSHEP model was used to assess potential impacts from the stream diversions which included the loss of instream habitat from constriction or diversion of stream flow, creation of barriers to stream animal upstream movement and entrainment of downstream drifting larvae. Four scenarios associated with the EMI Aqueduct System in the East Maui streams were addressed, including:

1. Natural Condition: This was upper boundary comparison scenario in which all diversions were modeled as closed with no water diversion and no impact on passage or entrainment of animals. This was the maximum available habitat units predicted.

2. Full Diversion: This was the lower boundary comparison scenario where all diversions in this scenario were modeled as fully open or diverting 100% of available low flows. The low flows, roughly analogous to the stream's baseflow, are critical to protecting instream habitat for stream species. The diversions and aqueduct system were built to capture 100% of normal low flow plus some smaller amount of storm runoff. Hawaiian streams are "flashy" where discharge rises quickly in response to rainfall and then quickly falls back to low flow conditions. When low flow conditions persist and overall diversion amounts do not exceed the conveyance capacity of the aqueduct, the streams can be dewatered below the diversions resulting in negative impacts on species habitat and passage. This scenario was intended to represent the diversion conditions found during sugar cane production.

[1] The DEIS identifies 37 streams associated with the License Area. 36 streams were identified in the CWRM D&O associated with the License Area. Two of these streams, Kualani and Ohia streams were not included in the HSHEP model as they were not diverted by the EMI Aqueduct System and Palauhulu Stream is a tributary of Piinaau Stream and thus was combined with Piinaau Stream. Puakea Stream was not mentioned in the CWRM D&O and therefore was not assessed in the HSHEP model This resulted in 33 distinct streams impacted by the EMI Aqueduct System.

3. 2018 IIFS: This scenario represented the flow conditions as described in the 2018 Interim Instream Flow Standard (IIFS) which included 24 streams and mandated restoration of flows in all but three streams. Four main types of flow restoration were mandated, including: Full-flow restoration, Habitat-flow restoration, Connectivity-flow restoration, and No-flow restoration. The diversion amount was estimated as available flow after compliance with the 2018 IIFS.

4. No action alternative or "30% remaining flow diversion": This scenario represented the long-standing agreement that "government owned waters" from the License Area amounted to 70% of streamflow, and the remaining 30% of the streamflow emanated from private/A&B/EMI lands. Thus, the No-Action alternative is the diversion of 30% of water available at the Honopou Stream boundary after compliance with the IIFS. This No-Action description is not directly translatable into the HSHEP model as the model requires specific diversion conditions at each diversion not an aggregate amount from a group of diversions. Therefore, this scenario assumed that 30% of remaining low flow discharge was diverted at each individual diversion after complying with the IIFS.

These scenarios allowed for the comparison and quantification of the changes in suitable habitat for native stream animals as a result of the different flow modifications.

The HSHEP Model project on the East Maui streams focused on assessing and quantifying suitable habitat under different flow scenarios. TRUTTA surveyed 35 diversion locations to include a range of habitat, biota, and diversion conditions to help ground-truth the HSHEP model. This report specifically addresses the 33 License Area streams and reports all model inputs and results for these streams associated with the four water management scenarios.

The License Area streams designated as Full Flow Restoration streams in the 2018 IIFS were: Makapipi, Waiohue, West Wailuaiki, Wailuanui, Waiokamilo, Piinaau (and its tributary Palauhulu), Hanehoi (Huelo/Puolua), and Honopou Streams. The full-flow restoration streams were some of the largest streams, with the majority of the lower and stream reach habitats found in this group. The primary reason for full-flow restoration was not the improvement of instream habitat for stream animals, but rather the downstream passage of water for customary and traditional uses (mostly taro cultivation) by downstream communities. While not the primary reason, full restoration of flow does provide instream habitat benefits for the native amphidromous stream animals. After flow restoration as defined by the 2018 IIFS, approximately 96.7% of native stream animal habitat units were estimated to exist with a few percentages more (98.4%) under the 30% remaining flow diversion scenario.

The License Area streams designated as Habitat (H_{90}) Flow Restoration streams in the 2018 IIFS were: Kopiliula, East Wailuaiki, Honomanu, Punalau/Kolea, and Waikamoi Streams. This group of streams was mandated to have approximately 64% of the baseflow restored specifically to improve instream habitat for native stream animals. Full diversion eliminated 49.9% of the habitat units naturally occurring in this group of streams. The restoration of 64% of the baseflow increased available habitat units to 77.1% of the naturally available habitat units. Under the 30%

remaining flow diversion scenario, the restored habitat was 91.1%. At these base flow restoration levels, nearly all physical instream habitat is restored, with the habitat unit losses due to entrainment of animals as they passed the diversion locations.

The lease-area streams designated as Connectivity-Flow Restoration streams in the 2018 IIFS were: Hanawi, Kapaula, Paakea, Nuaailua, Haipuaena, and Puohokamoa Streams. Within the group of stream designations for connectivity flows, two subgroups were observed. The first group contained a spring fed streams, Hanawi and Kapaula, while the second group contained the remaining streams. The spring-fed streams had consistent baseflow downstream of the diversion as a result of the spring inputs. As a result of the additional baseflow, the streams supported high numbers of native stream animals below the springs and had higher amounts of habitat units predicted from the HSHEP modeling for most native streams animals than most East Maui Streams. The second group of streams within the Connectivity-Flow Restoration group, Paakea, Nuaailua, Haipuaena, and Puohokamoa Streams, were streams without springs or obviously gaining reaches. Approximately 189,000 m² of the 301,000 m² available habitat units are found within Puohokamoa Stream. One difficult aspect with restoring habitat units through flow restoration in Puohokamoa Stream was the multiple levels of diversions on the stream. Puohokamoa Stream has 3 major (Spreckels, Wailoa, and Manuel Luis Ditches) and 5 minor diversions. While flow restoration may improve habitat in the stream, it may be more difficult to achieve given the number of diversions located on this stream.

The lease-area streams designated as No-Flow Restoration streams in the 2018 IIFS were: Waiaaka, Ohia/Waianu, and Wahinepee Streams. Ohia Stream is undiverted by the EMI Aqueduct System so natural flow conditions already exist. Waiaaka and Wahiepee Streams were considered intermittent in the DAR stream GIS data layer and thus, by definition within the HSHEP model rules, did not contain habitat units for native amphidromous stream animals that would be impacted by baseflow reduction. The standard of No-Flow Restoration appeared appropriate for these streams as instream habitat conditions are likely similar among any flow scenario.

The License Area includes streams that were not the subject of the 2018 IIFS decision but are diverted into the EMI Aqueduct System. These non-IIFS streams were located on the western side of the East Maui stream group. These streams have more extensive diversion systems than streams to the east of Piinaau. Most of the non-IIFS stream were diverted at four levels by Wailoa and New Hamakua Ditches at higher elevations and Spreckels, Center, Lowrie or Haiku Ditches at the lower elevations. Under the Full Diversion Scenario only 15% of the habitat units remain than compared to the Natural Flow Scenario in this group of streams. The loss of habitat was both from loss of instream habitat to water diversion and to passage and entrainment issues at each diversion. The 30% Diversion Scenario returned the habitat units available to 34%. Under this scenario, a wetted pathway would exist to the ocean, but there would still be substantial entrainment of larvae in the multiple diversion ditches. Increased restoration of the flow at the lower diversions may be a better practice than partial diversion of flow at all diversions. This strategy would allow diversion of water at higher elevations where less habitat naturally exists and decrease passage and entrainment impacts at lower diversion where more native stream animals will interact with the diversions.

In general for the native damselflies, the restoration baseflow would increase habitat downstream of the diversions which may be suitable for the species. While it is not clear how important the main channel habitat is for these species, the conditions will be far more natural than the highly diverted conditions immediately below the diversion under the full-diversion scenario. The improved baseflow throughout all reaches downstream would decrease standing water habitat within the stream for the introduced mosquito species.

Overall, the combination of field surveys and habitat modeling supports the IIFS flow restoration scenario in improving instream habitat conditions for native amphidromous stream animals. While suitable habitat is fundamental for a species' persistence and is the focus of the HSHEP model, it may not be the only thing that may affect species populations. Other factors, such as pollution, disease, or competition with introduced species may also influence the observed distribution and densities of native animals yet understanding the natural distribution of animals without the presence of these additional factors is still important. From a habitat availability perspective, the 2018 IIFS does a good job at improving instream habitat over a wide range of streams.

INTRODUCTION

The East Maui Irrigation (EMI) Aqueduct System supplies water to some 30,000 acres of agricultural land in Central Maui and serves more than 30,000 Upcountry Maui residents and farmers. The EMI Aqueduct System was built between 1876 and 1923 to collect and deliver surface water to sugarcane fields in Central Maui (CWRM D&O 2018). Currently, the EMI Aqueduct System operates under one-year revocable permits from the State. In an effort to allow the State to issue long-term water leases for the streams within the License Area via an auction process, Alexander and Baldwin, Inc (A&B), contracted the consulting firm Wilson Okamoto Corporation to develop the required Environmental Impact Statement of the surface water diversions. The EMI Aqueduct System has diverted water in its current configuration for nearly 100 years and baseline environmental condition studies (including the distribution and habitat of native stream animals) prior to its construction do not exist. To better understand the impact of the surface water diversion on native stream animals and their habitats, Trutta Environmental Solutions, LLC. (TRUTTA) was contracted to develop a Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model to assess impacts on 33 streams[2] associated with a Water Lease receiving the amount of streamflow diversion allowed under the 2018 Interim Instream Flow Standard (IIFS) (Figure 1).

Changes to the naturally occurring habitat brought about by man's modification of the environment may have a positive or negative effect on the quantity or distribution of a species' suitable habitat. The HSHEP model was designed to quantify how various man-made changes affect native Hawaiian amphidromous stream animals and is based on statewide observations of these animals' distribution and habitat. The HSHEP model considers the primary impacts of surface water diversion, which include loss of instream habitat from constriction or diversion of stream flow, creation of barriers to stream animal upstream movement and entrainment of downstream drifting larvae. While suitable habitat is fundamental for a species' persistence and is the focus of the HSHEP model, it is not the only thing that may affect species populations. TRUTTA fully realize that other factors, such as pollution, disease, or competition with introduced species may also influence the observed distribution and densities of native animals yet understanding the natural distribution of animals without the presence of these additional factors is important. Providing managers with the ability to assess change to native species habitat with respect to flow modifications, watershed development, or in-channel structures is important in quantifying the positive or negative implications of various actions. The HSHEP model was intended to capture the major aspects of native stream animal ecology, the typical geomorphology of Hawaiian streams, and common modifications to the environment within a single model.

[2] The DEIS identifies 37 streams associated with the License Area. 36 streams were identified in the CWRM D&O associated with the License Area. Two of these streams, Kualani and Ohia streams were not included in the HSHEP model as they were not diverted by the EMI Aqueduct System and Palauhulu Stream is a tributary of Piinaau Stream and thus was combined with Piinaau Stream. Puakea Stream was not mentioned in the CWRM D&O and therefore was not assessed in the HSHEP model This resulted in 33 distinct streams impacted by the EMI Aqueduct System.

The HSHEP model for the East Maui streams addressed multiple scenarios associated with the diversion systems. The first scenario was the natural-flow scenario. In this scenario, the modeled diversion impact was removed to create an estimate of the naturally available habitat for the stream species. The second scenario was the full-diversion scenario. Under this scenario, stream diversions were modeled at maximum diversion capability as was the case during the sugar cane cultivation period. The third scenario modeled the flow conditions described by the 2018 Interim Instream Flow Standards (IIFS) as determined by the State of Hawaii. The final scenario was the No Action Alternative. This scenario represented the long-standing agreement that "government owned waters" from the License Area amounted to 70% of streamflow, and the remaining 30% of the streamflow emanated from private/A&B/EMI lands. Thus, the No-Action alternative was the diversion of 30% of water available at the Honopou Stream boundary after compliance with the IIFS. This No-Action description was not directly translatable into the HSHEP model as the model requires specific diversion conditions at each diversion not an aggregate amount from a group of diversions. Therefore, this modeled scenario assumed that 30% of remaining discharge was diverted at each individual diversion after complying with the IIFS.

The HSHEP modeling approach applied on this project was developed for, applied on, and critically reviewed for use in Hawaiian streams. The HSHEP model approach has been used extensively in Hawaii, including for instream flow determinations on East and West Maui streams (Parham et al. 2009, Parham 2013a), and Waimea River, Kauai (Higashi and Parham 2016), for hydropower impact assessment on Wailua River, Kauai (Parham 2014), for flood mitigation impact assessment on the Ala Wai Streams, Oahu (Parham 2015b, c) and for other stream assessments across the state. In addition, the integrated field surveys and HSHEP approach underwent and passed formal professional review by the US Army Corps of Engineers (USACE) for its application on the Ala Wai Streams Flood Mitigation Project (Parham 2015a).

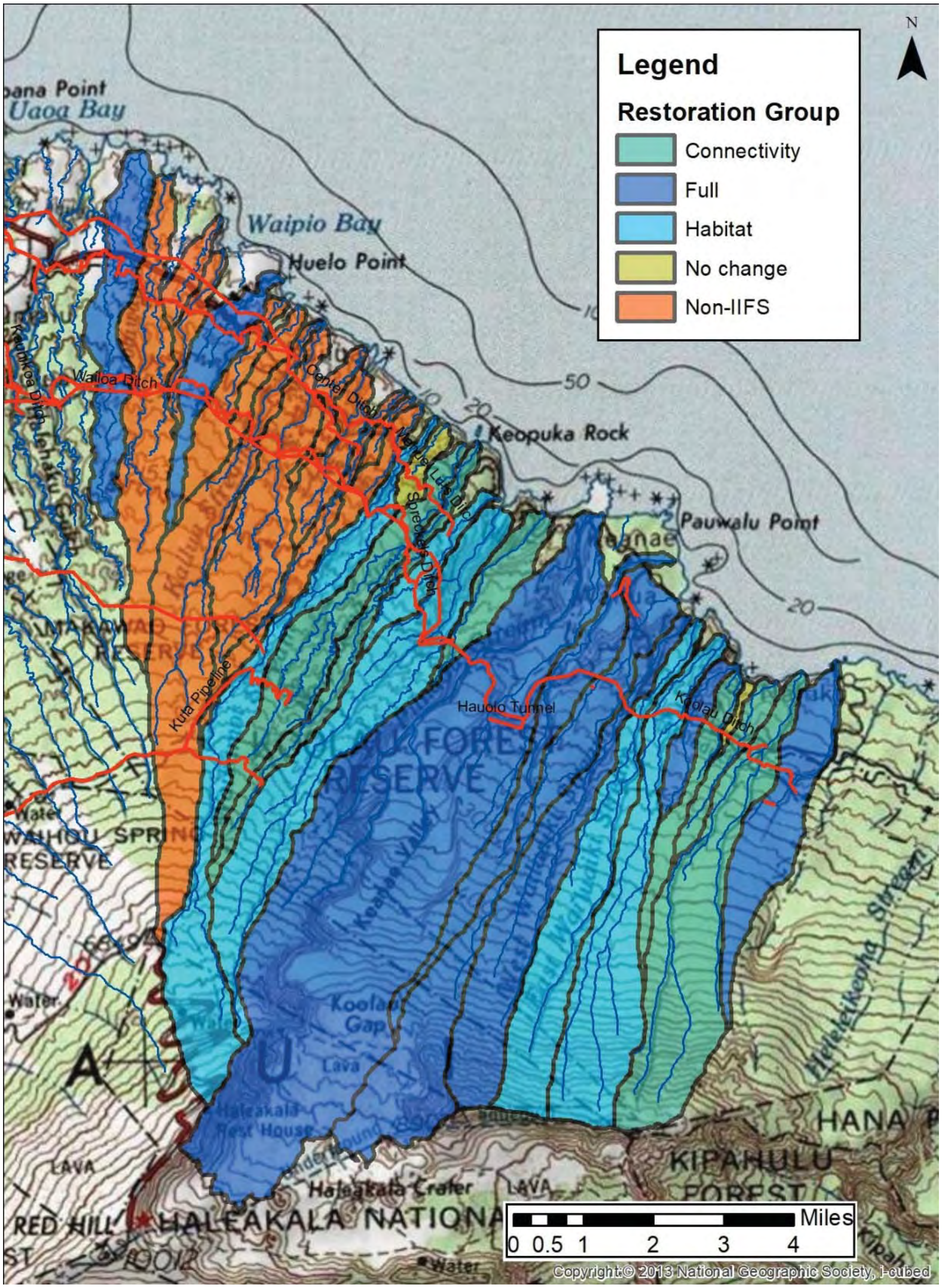


Figure 1: The 33 East Maui streams and watersheds associated with the EMI Aqueduct System. Colors correspond to the 2018 IIFS flow restoration status.

GOAL

The primary goal of this project was to quantify the impact of the stream diversions on suitable habitat for native stream animals in 33 East Maui streams under various diversion scenarios using the HSHEP model integrated with site-specific habitat, biota and diversion conditions.

OBJECTIVES

To achieve the goal, the HSHEP Model project on the East Maui streams focused on assessing and quantifying suitable habitat under different flow scenarios.

To complete these objectives, the following steps were taken:

1. *Conduct Field Surveys to improve understanding of current field conditions: (results in Appendix 1)*

    a. *Habitat Assessment*: Gathered field data on instream flow conditions and stream habitats near diversions using the High Definition Stream Survey (HDSS) method.

    b. *Diversion Assessment:* Conducted barrier assessments of each diversion to determine type and likely impact on native species.

    c. *Biotic Assessment:* Gathered data on the populations of native stream animals using the High Definition Fish Surveys (HDFS) to document biota in survey segments above and below diversions.

    d. *Field Survey Data Classification:* Organized and classified field survey data into categories for use in HSHEP model.

2. *HSHEP Model Assessment*: This report addresses all 33 streams within the License Area, including the streams that were the subject of the CWRM 2018 IIFS Decision and Order and streams that were not, but are within the License Area and diverted by the EMI System, and reports all model inputs and results for these streams associated with the four water management scenarios. To complete this task, TRUTTA:

    a. Updated to the HSHEP modeling process into R programming language.
    b. Created the source data and processing steps for all watersheds, streams, stream segments, and diversions in the system.
    c. Developed new water flow calculations with respect to the published USGS flow regression relationships for East Maui.

d. Ran the full HSHEP model.
e. Quantified suitable habitat units for native stream animals associated with the following scenarios:
    i. No Diversion,
    ii. Full Diversion,
    iii. 2018 IIFS
    iv. 30% Remaining Flow diversion
f. Documented HSHEP model results for the 33 streams with the License Area.

METHODS

FIELD METHODS

Habitat Assessment

The focus of the habitat assessment to support the HSHEP model was to document instream conditions both above and below stream diversions. We collected water depth, habitat type, substrate, and stream width measures as these can be converted into suitability criteria and estimates of overall habitat area. In addition to the habitat measures described below, stream discharge was measured upstream and/or downstream of the diversion to help document the proportion of the flow diverted.

To assess habitat availability, the High Definition Stream Survey™ (HDSS) method was used to collect, classify, and analyze the data required for this project. In general, the HDSS approach followed a standardized series of steps that promotes rapid, systematic collection and processing of large amounts of stream conditions information (Figure 2). Following the general HDSS process ensured a successful project.

Figure 2: The standardized HDSS project flow chart.

Due to the narrow and shallow streams being surveyed, our backpack-mounted HDSS system was the primary data collection platform used during the surveys to collect habitat data. (Figure 3). Data collection is contingent on water flow, so field work timing was adjusted to avoid rain and high stream flows as much as possible.

Figure 3: Brett Connell using Backpack HDSS on Paakea Stream, Maui. The GPS-linked video cameras are image stabilized to dampen the bounces associated with walking in a stream.

The backpack-mounted HDSS system has the following capabilities:

- 4-channel video recording (4 utilized for this project)
- four separate 64 GB SDXC cards in an array of four video streams in four separate files
- 4 above-water cameras
    - forward facing
    - streambank left
    - streambank right
    - down-looking for substrate classification
- Garmin GPS receiver with GLONASS capabilities and WAAS differential correction
- 1- to 3-meter ultimate accuracy
- optimized for speeds less than 1 mph

After the data was collected in the field, it was post-processed using HDSS Video Coder Software (Figure 4), Microsoft Access, Microsoft Excel, and ArcGIS. Data was classified for approximately each meter of the stream longitudinally. Given the primary goal of quantifying habitat, the following variables were classified:

- Water Depth
- Habitat Type (riffle, run, pool, side pool, plunge pool, cascade, falls, etc.)
- Primary Substrate Size Class (using Modified Wentworth Substrate Classification System compatible with the DAR's animal habitat surveys – fine, sand, gravel, cobble, boulder, and bedrock)
- Percent wetted stream width
- Presence of stream channel modifications

Water Depth

The Water Depth category captured the thalweg depth for the main flow of the stream channel. The thalweg can be considered the center of the main flow and is usually the deepest depth across the stream channel. The wading poles (which can be seen in the down-looking video) are set at 1 ft. at the first black joint and 2 ft. at the second joint for reference for the classifier (Figure 5). In deeper sections, verbal documentation of depths by the surveyors was noted for reference. The water depth was classified according to the following categories: Dry, < 1 inch, 1-3 inches, 3-6 inches, 6-12 inches, 12-24 inches, 24-36 inches (2-3 ft. deep), 36+ inches (>3 ft. deep), and Unknown.

Habitat Type

Habitat type is one of the primary measures in describing instream habitat and was classified as (riffle, run, pool, side pool, plunge pool, cascade, pocket water, or falls) from the assembled HDSS video primarily concentrated on the forward view. For example, Figure 5 shows an example of a run. Habitat types change depending on amount of water in a river.

In general, the habitat types classified from the HDSS videos were compatible with those habitat types used by DAR in their habitat and fish surveys.

Substrate

Substrate is a typical classification variable in habitat suitability studies and is mostly determined by high flow events. The high flow events have enough power to move boulders and scour out pools. For example, Figure 5 shows cobble substrate. Other substrate types included were fine sediment, sand, gravel, boulders and bedrock.

Stream Width

The stream width was determined by visual classification using the HDSS video. The width was measured to better determine the area of the habitat units observed from the imagery.

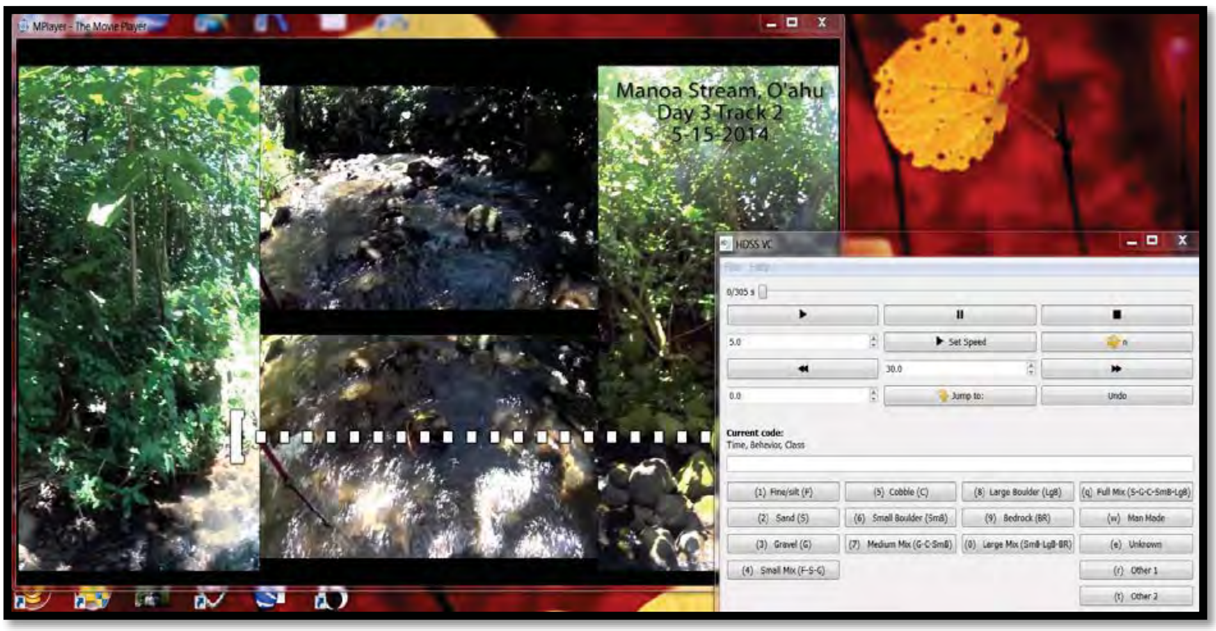


Figure 4: HDSS Video Coder V2.0 software used for systematic classification of video of streambank and stream bottom conditions. The software is easily customizable to allow appropriate classification systems to be used on a project. This example is from a US. Army Corps of Engineers Flood Control project on Oahu, HI.

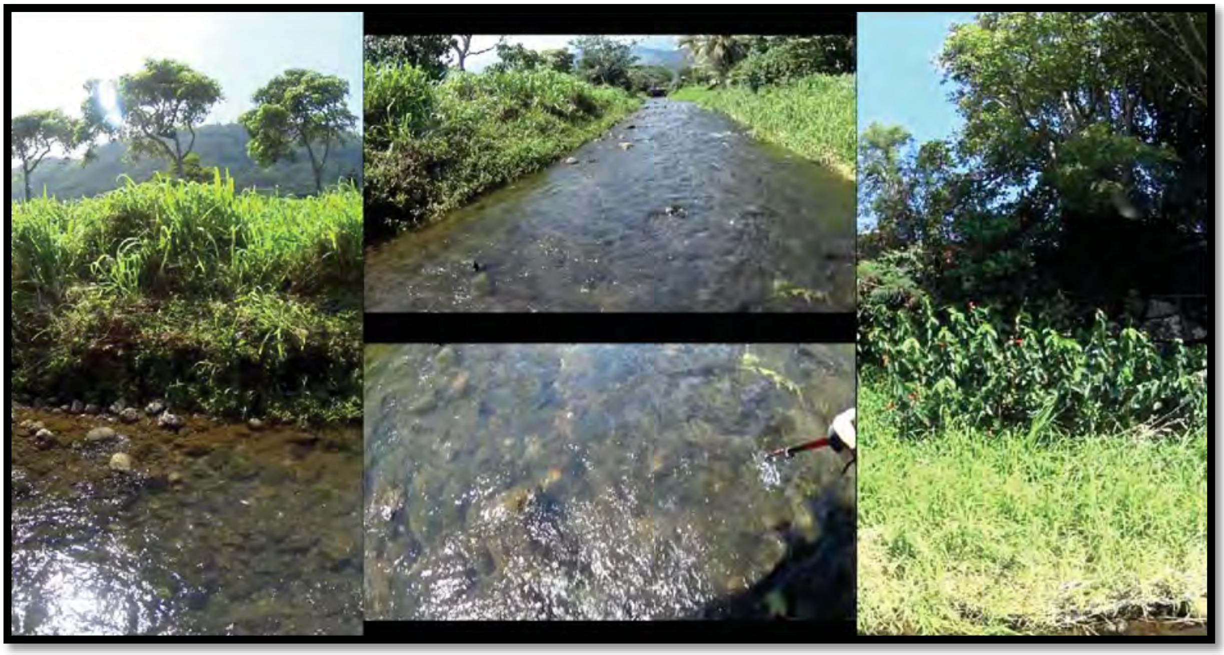


Figure 5: An example of the HDSS video from Manoa Stream, Oahu.

Diversion Assessments

To document the site-specific conditions at stream diversions, the DAR barrier assessment methodology was followed. The barrier assessment method has a standardized approach that allows the type, size, potential for modification and other factors to be systematically documented for each diversion. To convert the field information into data usable for the HSHEP model, the impacts of barriers and entrainment in stream diversion were determined by classifying the diversion into a type and then estimating the effects based on the type. For example, the main barrier types are:

> Stream mouth barriers – These barriers are the result of no water flow in the terminal stream segment. These barriers have two possible conditions, either open or closed. If baseflows are zero in the terminal segment, then a barrier is considered closed. If any flow is calculated to be present in the terminal segment, then the barrier is considered open.
>
> Side Diversion – This type of diversion removes water from the stream through a side intake structure. The water in a natural stream channel flows downstream past the diversion and a portion is removed by the intake. These side diversions typically have a small dam to help increase the amount of water diverted. Both ditch and auwai diversion can fall into this group. Downstream and upstream entrainment is modeled with respect to the amount of water diverted. Upstream entrainment may be lower because animals moving upstream are moving against the current and this may lead them upstream as

opposed to downstream into the diversion. With that said, at high diversion rates, some animals will get entrained.

Bottom Grate Diversion – This diversion type removes water from a grate covered channel that usually spans the stream channel bottom. Bottom grate diversions are typically found on larger stream diversions and are sized to remove 100% of baseflow. Downstream and upstream entrainment rates are modeled with respect to the portion of base flow diverted. Upstream entrainment is higher than with side diversion as upstream moving animals are easily trapped in the diversion as they try to pass over the bottom grate.

Entrainment rate calculation for diversions - The primary barrier issue modeled with diversions is entrainment of migrating animals. Entrainment is directly related to the proportion of water removed by the diversion. When 100% of baseflow is diverted, the entrainment is modeled at 80%. This would represent the entrainment of all animals drifting downstream in the baseflow and leaves a portion of the animals at higher flows that overtop the diversion without entrainment. At diversion rates lower than total baseflow removal, the entrainment value is a portion of baseflow (Q_{70}) remaining after the diversion compared to natural baseflow (Q_{70}) multiplied by the maximum entrainment rate.

BIOTIC SURVEYS

High-Definition Fish Surveys (HDFS)

The High Definition Fish Survey (HDFS) approach was used to document biota in the survey segments. HDFS utilizes pole-mounted, high-definition, underwater video cameras to capture images of fish or other aquatic animals at a specific location (Figure 6). The underwater cameras are geo-referenced so that specific time and place information is recorded in conjunction with all video observations.

In general, the HDFS sample was considered a point or timed sample. The cameras were moved into position, slowly lowered to the bottom, and then left in position for approximately 30 seconds to capture a sample of animals at that location (Figure 7). In some locations, the camera was moved slowly to the next position without removing it from the water. This process was repeated at sites distributed evenly throughout the available habitat. In locations where it was too deep and wide to wade a stream, TRUTTA snorkeled the stream with a hand-held video camera on a 3 ft pole. This allowed us to gather a visual record of the habitat and species present that could be processed in a similar method to the other HDFS approach.

To document the animals observed in the videos, the HDSS Video Coder software with a list of potential animal species was used. Additional species, if observed, were listed as Other1, -2, or -3 and then identified after the classification process. This allowed a single standard classification approach to be used for all survey video. The potential Hawaiian Stream species list included (Figure 8):

Native Fishes: ʻOʻopu nākea (*Awaous stamenius*), ʻOʻopu naniha (*Stenogobius hawaiiensis*), ʻOʻopu nōpili (*Sicyotperus stimpsoni*), ʻOʻopu alamo'o (*Lentipes concolor*) ʻOʻopu akupa (*Eleotris sandvicensis*), Aholehole (*Kuhlia xenura*), Mullet (*Mugil cephalus*).

Native Crustaceans and Mollusks: ʻŌpae ʻoehaʻa (*Macrobrachium grandimanus*), ʻŌpae kalaʻ'ole (*Atyoida bisulcata*), Hīhīwai *(Neritina granosa*), Hapawai (*Neritina vespertina*), Newcomb's snail (*Erinna newcombi*).

Introduced Fishes: Armored Catfish (*Hypostomus c.f. watawata)*, Bristlenose Catfish (*Ancistrus c.f. temmincki*), Bronze Corydoras (*Corydoras aeneus),* Liberty Molly (*Poecilia sp. hybrid complex)*, Green Swordtail (*Xiphophorus hellerii)*, Guppy (*Poecilia reticulata)*, Mosquitofish (*Gambusia affinis*), Blackchin Tilapia (*Sarotherodon melanotheron)*, Convict Cichlid (*Amatitlania nigrofasciata)*, Smallmouth Bass (*Micropterus dolomieu)*, Carp (*Cyprinus carpio),* Goldfish *(Carassius auratus),* Dojo *(Misgurnus anguillicaudatus),* White Cloud Mountain Minnow *(Tanichthys albonubes)*, Rainbow Trout (*Oncorhynchus mykiss*).

Introduced Crustaceans, Mollusks, and Amphibians: Tahitian prawn (*Macrobrachium lar*), Grass Shrimp (*Neocaridina denticulata sinensis*), Crayfish (*Procambarus clarkii*), Cane Toad (*Bufo marinus*), Bull Frog (*Rana catesbeiana*), Wrinkled Frog (*Rana rugosa*).

Insects: TRUTTA captured pictures of damselfly and dragonfly adults and larvae for identification whenever they were observed. Although, small or cryptic insect populations typically are not surveyed with this technique, damselfly and dragonfly adults and larvae were large enough to observe using video capture techniques.

During the video classification, a start code was inserted when the camera was in position. Next, all individuals of all species were recorded, and then a stop code was inserted. For each sample, the habitat type was recorded. This process allowed underwater video samples to be linked with the appropriate GPS data for that location.

When density estimates for stream animals were needed, an estimate of the area observed was determined by recording average depth and width of field captured in the sample area. These two measures were multiplied together to get sample site area. The total number of each species observed within each habitat type for the different areas surveyed was divided by the area of that habitat type to get the species density within each habitat type.

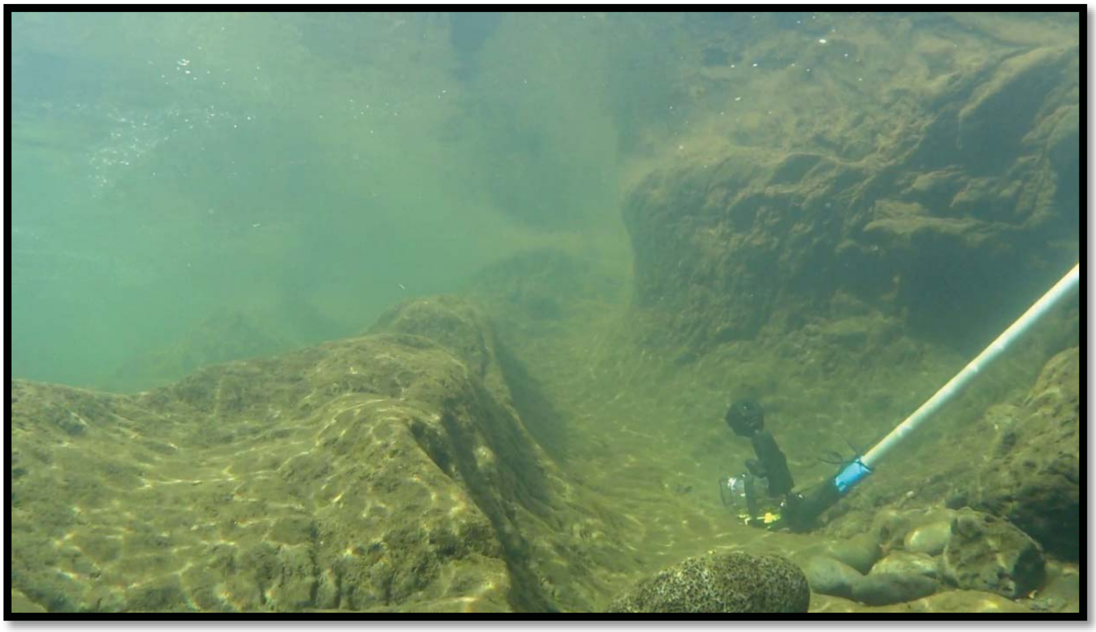


Figure 6: Underwater geo-referenced video camera with external video light used for the HDFS observations.

Figure 7: Example of HDFS surveys in Manoa stream, Oahu.

	
Native fish, *Awaous stamenius,* in a stream pool in I'ao Stream, Maui.	Native fish, *Sicyopterus stimpsoni*, on boulder substrate in I'ao Stream, Maui.
	
Native species, *Kuhlia xenura*, in the lower reach of I'ao Stream, Maui.	Introduced swordtails, *Xiphophorus hellerii*, in I'ao Stream, Maui.
	
Introduced Blackchin tilapia, *Sarotherodon melanotheron*, over gravel substrate in Palolo Stream, Oahu.	Introduced armored catfish, *Hypostomus c.f. watawata in Waiawa Stream, Oahu.*

Figure 8: Examples of stream animals observed during HDFS projects on various Hawaiian Streams.

MODELING

HSHEP Model

The HSHEP model was an outgrowth of a history of collaboration among biologists at Hawaii Division of Aquatic Resources (DAR) and researchers at various universities, agencies, museums, and private companies. The collaborative effort focused on understanding the different aspects of the ecology and management of amphidromous stream animals (Fitzsimons and Nishimoto 2007). The HSHEP model was an attempt to quantify how various man-made changes affect native Hawaiian stream animals. The HSHEP model was intended to capture the major aspects of native stream animal ecology, the typical geomorphology of Hawaiian streams, and common modifications to the environment within a single model. Additional factors outside of habitat can be modeled with the HSHEP approach but need additional modeling steps that are currently best addressed on a case-by-case basis. The HSHEP model provides water managers the ability to assess change to native species habitat with respect to flow modifications, watershed development, or in-channel structures and is important in understanding the positive or negative implications of various actions.

The HSHEP model followed the overall Habitat Evaluation Procedure (HEP) model concepts developed by the U.S. Fish and Wildlife Service (USFWS) to evaluate the quantity and quality of habitat available for a species of concern (USFWS 1980 a,b, USFWS 1981). In general, a Habitat Evaluation Procedure (HEP) model has several characteristics:

1. It is a habitat-based assessment method.
2. It assumes that habitat quality and quantity are related to the number of animals using a habitat over the long term.
3. It uses measurable attributes of habitat quality and quantity to create relationships between habitat suitability and animal occurrence and density.
4. It converts suitability relationships into standardized Habitat Suitability Indices (HSI) that encompass the range of observed habitat conditions.
5. The HSI values range from 0 (unsuitable habitat) to 1 (most suitable habitat).
6. It multiplies the habitat quality (value from the HSI) with the habitat quantity (area) to determine overall Habitat Units (HU) within the area of concern.

As a result of the model design, HEP impact analyses were intended to allow the user to:

1. Provide defined suitability-based estimates of HU within a study area,
2. Provide impact assessments of the changes of HU within the study area under different management scenarios,
3. Provide objective comparable unit measures for multi-site comparisons,
4. Quantify changes in HU to be annualized and comparable with other cost/benefit analyses,

5. Create plots of the distribution of HU in map-based formats (GIS analyses) to address issues of habitat fragmentation or connectivity.

The HEP user manual describes a HEP model like this: “HEP is a convenient means of documenting and displaying, in standard units, the predicted effects of proposed actions.” USFWS designed HEP to be a legally defensible, standardized format for impact assessment in natural resource settings (USFWS 1980 a). While HEP models have been developed and used for impact assessment nationally for hundreds of species of birds, mammals, and fish, this is the first HEP model to assess changes in stream animal habitat in Hawaii.

Traditional HEP procedures were joined with multi-spatial modeling efforts for Hawaiian streams (Parham 2002, Kuamo’o et al. 2006, Parham 2008). The multi-spatial models address issues of scale in understanding differences in habitat availability and species distributions. For example, the presence or density of amphidromous animals is influenced by the location of the sample site within a stream. Similar habitats found near the ocean may have different species assemblages than habitats found further inland. Additionally, characteristics of different watersheds and their streams influence the observed species assemblages. For example, streams with terminal waterfalls have different species assemblages than streams without terminal waterfalls. By assessing suitability at multiple spatial scales, different aspects of amphidromous animal ecology were more appropriately modeled (Figure 9). As a result of the combination of the HEP method with multi-scale analysis, management issues were addressed on a site, stream segment, whole stream, or regional level. The HSHEP model is intended to be useful to assess the impacts of stream channel modification, flow alteration, land use change, climate change, stream restoration, and barrier modifications.

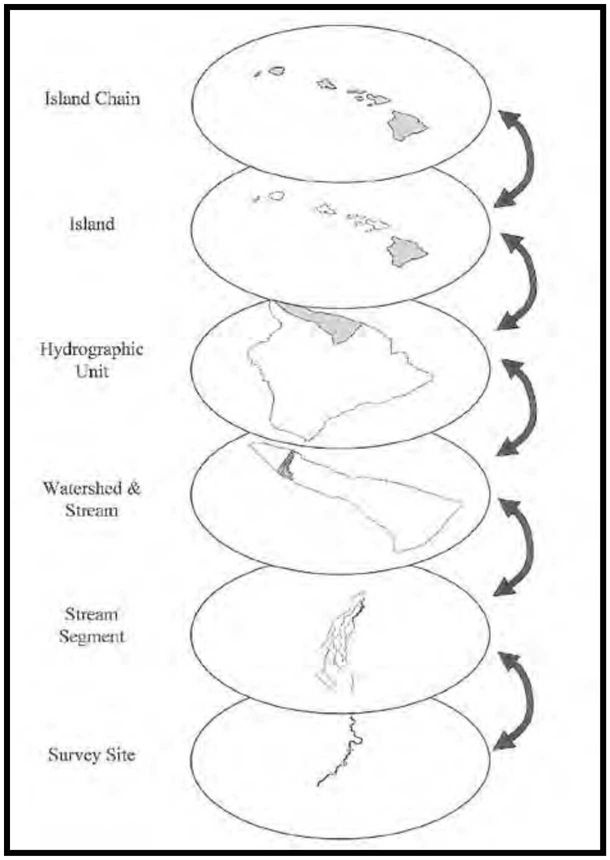


Figure 9: Spatially-nested hierarchy of the DAR Aquatic Surveys Database and predictive levels within the HSHEP model.

The latest description of the HSHEP model can be found in:

Parham, J.E. 2015. The Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model: Intent, Design, and Methods for Project Impact Assessment to Native Amphidromous Stream Animal Habitat. Submitted to Civil and Public Works Branch, U.S. Army Corps of Engineers, Honolulu District, HI. 178 pages.

The HSHEP Model uses published information for species distributions at the watershed and reach scale and combines it with local data from the habitat and biotic surveys. Stream animals' distribution and habitat use are documented using information stored in the DLNR-DAR Aquatic Surveys Database (2009). This represents over 13,000 survey locations and over 90,000 species observations. The database includes results from state surveys as well as those from federal, university, and private researchers. More than 370 different literature sources support the data contained within the DAR Aquatic Surveys Database. The HSHEP model leverages the data within the DAR Aquatic Surveys Database to develop quantitative measures of habitat use for native stream animals. For this project, the HSHEP model was created for the typical group of native freshwater fish and macroinvertebrates found in Hawaiian streams (Table 1).

Table 1: Native species habitat evaluated for this project.

Organism Type and Family	Scientific name	Hawaiian name
Freshwater fish (family Gobiidae)	*Awaous stamenius**	‘O‘opu nākea
	*Lentipes concolor**	‘O‘opu alamo‘o
	*Stenogobius hawaiiensis**	‘O‘opu naniha
	*Sicyopterus stimpsoni**	‘O‘opu nōpili
Freshwater fish (family Eleotridae)	*Eleotris sandwicensis**	‘O‘opu akupa
Freshwater shrimp (Crustacean) (family Atyidae)	*Atyoida bisulcata**	‘Ōpae kala‘'ole
Freshwater prawn (Crustacean) (family Palaemonidae)	*Macrobrachium grandimanus**	‘Ōpae ‘oeha‘a
Freshwater snail (Mollusk) (family Neritidae)	*Neritina granosa**	Hīhīwai

*Identified as “Species of Greatest Conservation Need” in the Hawaii Statewide Aquatic Wildlife Conservation Strategy (Meadows et al. 2005).

The selection of the highlighted set of amphidromous stream animals is appropriate in this case for several reasons:

- These species have been observed within the East Maui Watersheds.
- All of these species have a diadromous life history, meaning that they migrate from the freshwater stream to the ocean and back again (McDowall 2007). This potentially exposes the migrating animals to barriers in the stream pathway, entrainment into water diversion systems, and elimination of suitable habitat resulting from structures associated with the ditch system and its diversion.
- The DAR Aquatic Surveys Database has distribution and habitat use information for each of these species.
- The HSHEP model has habitat suitability indices developed for each of these species.

In addition to the species list above, three native damselflies (*Megalagrion xanthomelas*, *Megalagrion pacificum*, and *Megalagrion nesiotes*) and an introduced mosquito (*Culex quinquefasiatus*) habitats were also modeled to see how the water diversions may impact their population sizes. For these species, SWCA Inc. scientists provided the habitat descriptions to be used in the models. A summary of the descriptions along with generalized suitability model are as follows:

Megalagrion xanthomelas

Elevation Range: 0-1000 m (0-3280 ft.) above sea level.

Water Depth Range: Shallow (3-6 in deep) and sidepools.

Main Threat: Alien species and habitat loss due to stream de-watering for agriculture, invasive California grass (*Brachiaria mutica*), which forms dense stands that can eliminate open water. This species is also threatened by introduced species, particularly poeciliid fish, crayfish, and backswimmer bugs (Notonectidae). It may also be threatened by predation from introduced odonates, as introduced *Enallagma civile* and *Ischnura ramburii* have been observed preying on teneral adults at the Ninole Springs, Hawaii population site.

Known Locations: Maui - Ukumehame Stream, and near anchialine pools at La Perouse Bay.

Additional Notes: Lowland species, found in slow or standing water habitats, breeds primarily in coastal wetlands and lower or terminal stillwater reaches of perennial streams; In the absence of predators, especially introduced fish species, it can breed successfully in standing pools of intermittent mid-elevation streams, freshwater marshes, reservoirs, garden pools, and ornamental ponds. Adults do not disperse far from the nymphal habitat and lay their eggs in the tissues of aquatic plants found in slow reaches of streams and in stream pools.

Habitat Suitability: Adults Less than 1000 m elevation. Breed low reaches of perennial and intermittent streams. 10% of habitat in undiverted conditions (shallow (3-6 in deep) and side pools). Use opae habitat curve as suitable habitat will be rapidly restored as baseflow is returned to a stream.

Megalagrion pacificum:

Elevation Range: 0-800 ft. elevation above sea level.

Water Depth Range: Shallow water, temporary pools. Breeds in stagnant ponds. It prefers quiet pools away from the main channels

Main Threat: *Megalagrion pacificum* is threatened by habitat loss, predation by non-native fish, and the presence of the highly invasive California grass (*Brachiaria mutica*) which forms dense stands that can eliminate open water. Predatory fish and introduced backswimmers (Hemiptera: Notonectidae) as well as resource competition from introduced caddisflies.

Known Locations: Maui - Haipuaena, Hanawi, Keanae, Palikea and Kuhiwa Streams.

Additional Notes: Freshwater, seepage fed side pools along mid and terminal reach overflow channels of rocky upland streams. It is thought to prefer side pools on slow-moving streams that contain abundant native grasses and sedges. Unlike some congeners, it is entirely aquatic.

Habitat Suitability: Adults less than 250 m elevation. Breed in low reaches of perennial and intermittent streams. 5% of habitat is in undiverted conditions (slow-moving side pools). Use opae habitat curve as suitable habitat will be rapidly restored as baseflow is returned to a stream.

Megalagrion nesiotes:

Water Depth Range: The only known population occurs along a steep, moist, talus slope, densely covered with *Dicranopteris linearis* (uluhe) and *Rubus* sp. (blackberry). Adults are not associated with standing or flowing water, but prefer upland ridges, wet forests, and steep, moist, fern-covered banks. The habits of the nymphs are unknown, but based on adult behaviors, they are believed to be semi-terrestrial or terrestrial, inhabiting pockets of water at the bases of leaves of tropical plants or wet leaf litter.

Main Threat: This species is at high risk of extinction. *M. nesiotes* is threatened by the effects of invasive species, particularly habitat damage due to feral pigs and possibly from human tourism (hiking) activities in this area. If nymphs of this species are in fact semi-terrestrial, predation from introduced ant species such as the big-headed ant (*Pheidle megacephala*), the long-legged ant (*Anoplolepis longipes*), and the fire ants *Solenopsis geminita* and *Solenopsis papuana* may also be a threat. Natural disasters such as drought or hurricane could threaten the survival of *M. nesiotes*. Such a small population could also suffer loss of genetic variability due to inbreeding, resulting in reduced evolutionary fitness.

Known Locations: Maui - Only a single remaining population (of less than 1,000 individuals) of this species is known, found along East Wailuaiki Stream (stream is in license area), upslope of a busy highway (considered sub-optimal habitat for the species.) Additional colonies of this species may be scattered throughout the intermediate elevations of windward Maui, but have escaped detection due to the difficult topography, and the tendency of adults to fly low amid tangled undergrowth, in areas not typically searched for damselflies

Habitat Suitability: While this species is known from the area around East Wailuaiki Stream, the habitat description is not linked to the stream channel. Additionally, this area is above the diversion and thus will not change in any scenario. No habitat suitability model was created as it is unlikely to be impacted by water flow modifications.

Additional Notes: Little known about the biology of this species, but it is not associated with standing or flowing water. The only known population occurs along a steep, moist, talus slope, densely covered with *Dicranopteris linearis* (uluhe) and *Rubus* sp. (blackberry). Adults are usually seen perched on vegetation and fly slowly and only short distances. When disturbed, the adults actually fly into the tangled vegetation rather than up and away as in the aquatic Hawaiian damselflies. Although immature stages have not been found, based on the habitat and the behavior of the adults, it is believed that the naiads are terrestrial or semiterrestrial, occurring among the damp leaf litter.

Culex quinquefasiatus:

Elevation Range: 0-1500 m. elevation above sea level.

Water depth range: Moist, windward side of all main islands; *Culex quinquefasciatus* is a domestic to peridomestic mosquito associated with human residence and activity throughout most of its range (Subra 1981). In some remote insular environments, it has become established in natural areas. Larval habitats are, primarily, artificial containers and man-made impoundments such as ditches, ground pools, and stock ponds. In more natural areas larvae can be found in tree holes, rock holes, ground pools, stream margins, coconut husks and spadix sheaths. The larvae prefer eutrophic waters with a high organic content. Exceptionally high densities of larvae may be found in the septic water associated with oxidation ponds, sewage drains, cesspools, and septic tanks. Not found in flowing water. Breeds in ditches, pools, marshes, tin cans, buckets, barrels, soda cans, tires and any trash; Data indicate that agricultural lands and forest fragmentation significantly increase the probability of mosquito capture.

Known Locations: Maui - all streams.

Habitat Suitability: Less than 1500 m elevation. Not found in flowing water. 5% of habitat in undiverted conditions (slow-moving side pools). Created a relationship where habitat increases with decreasing baseflow: suitable habitat = 0.5*(1-(baseflow in stream)) + 0.5

HSHEP Modeling Process Improvement

The implementation of the HSHEP model in prior assessments of Hawaiian streams had generally been accomplished as single watershed models. When multiple watersheds were studied, a group of single watershed models were analyzed to determine the overall impacts. For the analysis of the EMI Aqueduct System, TRUTTA needed to change the modeling language to more effectively deal with the more complex multiple ditch and watershed system. To accomplish this, TRUTTA ported the entire model workflow to the statistical computing language R to improve on several aspects of the modeling process without any alteration to the model concept or calculation.

The conversion of the HSHEP model from a spreadsheet to the statistical computing language R provided several benefits:

- Improved Error Checking - Reducing the numerous spreadsheets required to implement calculations with the spreadsheet model to individual R scripts made determining the source of errors in the model more efficient.
- Increased Equation Readability - By explicitly stating the relationships among nodes and basins for each basin, interpretation of the model's calculations were greatly improved.
- Allowed for Real-time Testing - Since changes in inputs are easily read in to the established R-based model without needing additional manual editing, as is the case of the spreadsheet model, real-time testing and manipulation of inputs to the model and generation of outputs are much faster and there is a reduction in the 'hands-on' time which may introduce novel errors to the computations.
- Improved Documentation of Multiple Scenarios - The process to test multiple management scenarios is more efficient in R than in a spreadsheet. TRUTTA also created an output in spreadsheet format to further document the results.

Future applications of the HSHEP model for research into the optimal balance of water withdrawal, fish habitat, and other considerations in East Maui or in any Hawaiian stream will be greatly improved as a result of the benefits listed above and therefore, justified the transfer of the model and its calculations from a spreadsheet to the R programming language.

Data Sources

TRUTTA calculated stream discharge data for each basin by applying the USGS flow to basin characteristic equations (Gingrich 2005) and assigned the appropriate values to each basin (dash-dot delineated areas in Figure 10). We assigned values of habitat units available each species of conservation concern from past modeled data for the species (Parham et al. 2009). The values used for each 'node' – locations of the natural barriers and artificial diversions impacting stream flow that contributed to the irrigation system of East Maui – were a vector of the amount of water passed, entrainment potential, passage barrier potential, and a general value for additional impacts for both upstream and downstream effects. These values were determined for each node during field surveys and from historical records about the installation and purpose of the diversions.

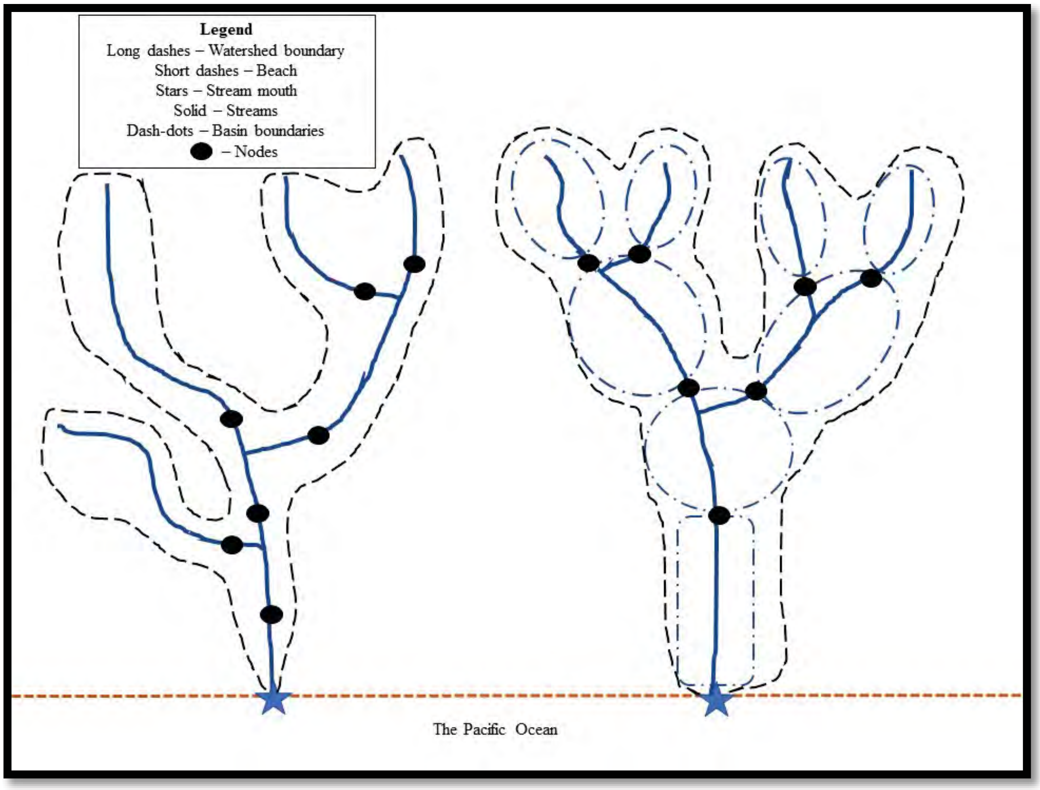


Figure 10: Conceptual schematic displaying the relationships among nodes, basins, and watersheds used to model the EMI Aqueduct System.

General Model Concept and Assumptions

We performed modeling of the water and habitat availability within the EMI Aqueduct System using several assumptions. The calculations for water availability assumed that the amount of water available in any basin was a measure of the water in that basin augmented by the amount of water passed from the basin immediately upstream. For example, the amount of water present in basin II in Figure 11 was modeled as the amount of streamflow measured in that basin, plus the amount of stream flow from basin III minus the percentage of stream flow from basin III that was filtered by node 3. If 100 units of water are present in basins II and III, and node 3 diverts 50% of flow, then the modeled amount of water present in basin II was 150 units (100 units + (100 units* 50% diversion)). This model assumption accounts for the facts that water passes downstream, and that East Maui streams are generally gaining streams, so that complete de-watering by an upstream diversion will not affect downstream basins beyond those immediately downstream. The model calculations to estimate habitat in each basin operated on the assumption that the production of a species in a basin was a function of the habitat in that basin, filtered by the upstream restrictions of any basins downstream and augmented by any habitat available for production from the upstream basins as filtered by the intervening node. As an example, using Figure 11, the amount of habitat available for production of a species in basin II is the amount of habitat in that unit multiplied by the upstream filtering effects and habitat present in basin I and nodes 1 and 2, plus the habitat available in basin III as filtered by the downstream passage/entrainment effects of node 3. These assumptions allow us to model the production of species of conservation concern from any basin while accounting for potential upstream and/or downstream effects due to diversions or other barriers, up to and including functionally preventing production in a basin due to complete de-watering or barrier passage (i.e. an undercut waterfall). For example, if node 2 represented an undercut waterfall in Figure 11, and thus prevented upstream migration of any species, the remaining habitat available in the upstream basins of the watershed (basins II-VI) would be modeled as 0 for non-insect species.

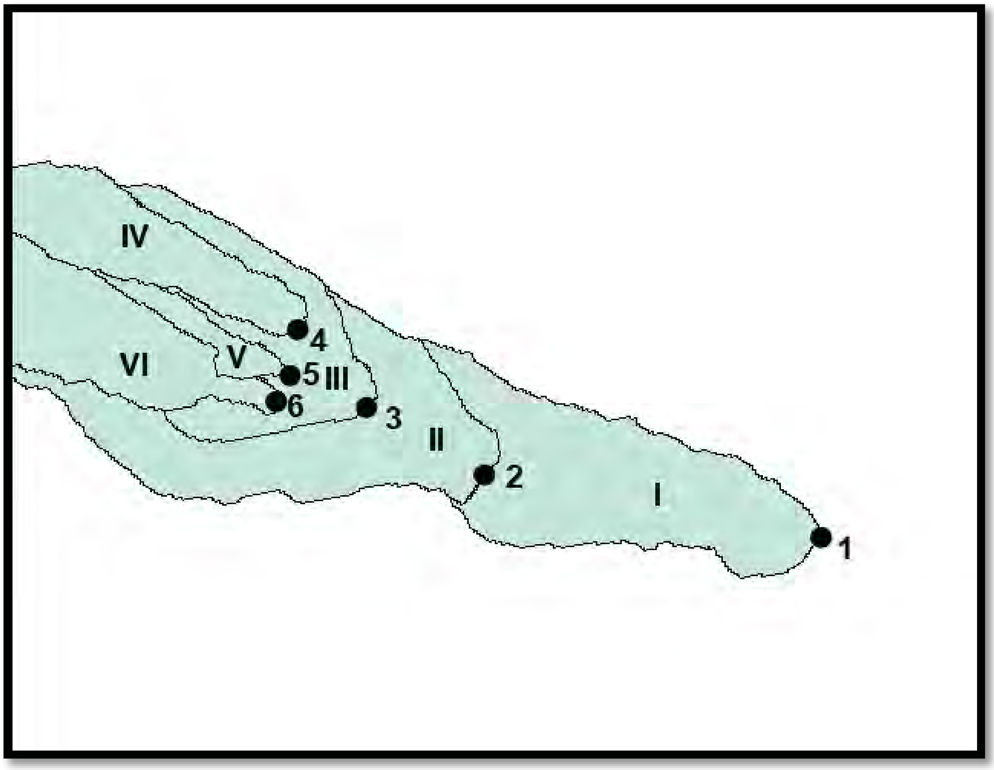


Figure 11: Node and basin relationship for branched stream system.

Data Aggregation

After we completed necessary ground-truthing and collection of new data from the field to validate instream habitat availability and diversion characteristics for all streams, we combined several variables for each basin defined in the EMI Aqueduct System to complete the dataset for modeling in a GIS. The underlying data in the GIS database can be updated with new information as it becomes available to provide new estimates as needed. This overall approach allows for current or modeled scenario conditions to be applied consistently to better understand the impact of water diversion or return at each individual diversion location across East Maui *(see also the information on grouping basins for model evaluation in the next section*).

Following the data aggregation process, we manually extracted the appropriate relationships among basins, watersheds, and nodes. We recorded the upstream and downstream basins and their associated nodes for every basin in East Maui from the GIS. Once we had compiled this dataset from the GIS, we next wrote two equations for every basin: one to calculate the habitat available in each basin, and one to calculate the amount of water found in each basin, both of which incorporated relationships from adjoining basins. We used these equations to model the effects of differing diversion rates on the habitat, biomass production, and water output of the EMI Aqueduct System.

Modeling Habitat and Water Production

We calculated the amount of available habitat in a basin for a specific species as:

$Habitat_{E(i)} = (Habitat_{SP(i)} * Node_{DS(i)}) * (Habitat_{SP(i-1)} * Node_{US(i-1)}) * (Habitat_{SP(i-2)} * Node_{US(i-2)})\ldots + (Habitat_{SP(i+1)} * Node_{US(i)}) + (Habitat_{SP(i+2)} * Node_{DS(i+1)})\ldots + (Habitat_{SP(i-N)} * Node_{US(i-N)})$

Where:

- i = the current basin
- i – 1 = the basin downstream of the current basin
- i +1 = the basin immediately upstream of the current basin
- $Habitat_{SP(i)}$ = the measured habitat for a species in the current basin
- $Habitat_{E(i)}$ = the total affected habitat of the current node, accounting for upstream and downstream influences
- $Node_{DS(i)}$ = the filtering value for the node at the downstream end of the current basin
- $Node_{US(i)}$ = the filtering value for the node at the upstream end of the current basin
- N = number of basins upstream or downstream of the current basin

In this model, the same node was the downstream node for the basin i+1, and therefore its downstream entrainment, diversion, etc., values were applied, or the upstream node for basin i, and so the values for the upstream direction were used.

To model the impacts of the node system on the water available in each node, and to account for the amount of water captured from the system under different management regimes, we also wrote equations for each basin. The equations to calculate the amount of water present in each basin (and its inverse, the amount of water captured from each basin) followed the form:

$Water_{E(i)} = Water_i + (Water_{(i+1)} * Node_{US(i)})$.

Where:

- $Water_i$ = amount of water present in the current basin
- $Water_{E(i)}$ = amount of water effected by upstream node

In this application, the $Node_{US}$ value is an atomic vector modeling for the percent of water passed from the adjacent upstream basin to the current basin through the diversion separating them.

The inputs required to model the habitat and affiliated production of freshwater species of interest of the East Maui system were the estimates of available habitat for each basin, a matrix of up- and downstream effects of each node, and any additional grouping variables for the outputs. To similarly model the water produced/retained in the system, the only inputs required are measures of the amount of water available in each basin (e.g., mean annual rainfall or mean annual flow, etc.) and the percentage of downstream water diversion of each node. The model results in both cases are aggregated by a grouping variable, so the outputs can be tailored to demonstrate impacts of management actions on an unlimited variety of arrangements of the basins in East Maui. For example, the results of the modeling on changes in habitat availability among the cases of full diversion, no diversion, and any intermediate case can be reported variously by watershed, species of interest, irrigation grouping, lease grouping, or other categorizations as assigned to the basins and watersheds by stakeholders.

RESULTS

GENERAL WATERSHED and BASIN DESCRIPTION

For consistency with other EIS reports and the CWRM IIFS D&O, TRUTTA was provided the following information regarding the stream names, License Area, and inclusion in the 2018 IIFS by the Wilson Okamoto Corporation.

The

Table 2 below lists streams considered to be within the License Area as presented in Table 1-2 in the EIS Preparation Notice (EISPN) dated February 2017. This table was prepared prior to the CWRM IIFS Decision and Order (D&O) issued on June 20, 2018. The table lists a total of 40 items, 39 of which are considered streams and one (1) of which is a waterfall (Waikani). In contrast, the CWRM IIFS D&O specified 36 streams in the License Area.

For purposes of the report, the IIFS D&O listing of streams and nomenclature will be used. The table below is a reconciliation of the EISPN table with the CWRM D&O listing. The items in bold are those that differ in some way from the CWRM IIFS D&O. The bolded items are explained in the Notes column.

Table 2: Comparison of EISPN and CWRM D&O Stream Lists

Table 1-2: License Area Streams (in ESPN February 2017)				
License Area	No.	Stream Name	Notes: Reconciliation with CWRM East Maui IIFS D&O	Revised Count
Nāhiku	1	Makapipi		1
Nāhiku	2	Hanawī		2
Nāhiku	3	Kapāʻula		3
Keʻanae	4	Waiʻaka	Referenced “Waiaʻaka” per D&O	4
Keʻanae	5	Paʻakea		5
Keʻanae	6	**Puakea**	The CWRM D&O did not mention this stream	
Keʻanae	7	Waiohue		6
Keʻanae	8	**Puakaʻa**	Referenced as “Kopili'ula (Puaʻakaʻa tributary) per D&O	
Keʻanae	9	Kopiliʻula		7
Keʻanae	10	East Wailuā-iki		8
Keʻanae	11	West Wailuā-iki		9
Keʻanae	12	**East and West Wailuānui**	Referenced “Wailuānui”perD&O	10
Keʻanae	13	**Waikani**	Waikani is a waterfall, not a stream; combined with Wailuānui above	
Keʻanae	14	Kualani	Referenced as “Kualani (or Hāmau)” per D&O	11
Keʻanae	15	Waiokamilo		12
Keʻanae	16	**Palauhulu**	Transposed sequence with Ohia (or Wainu) below	14
Keʻanae	17	**Waianu/ʻŌhiʻa**	Referenced as “Ohia (or Waianu)” per D&O and, transposed sequence with Palauhulu above	13
Honomanū	18	Piʻinaʻau	EISPN noted Pi'ina'au in the Honomanu License Area; D&O has it in Ke'anae License Area	15
Honomanū	19	Nuaʻailua		16
Honomanū	20	Honomanū		17
Honomanū	21	Kōlea/Punalaʻu		18
Honomanū	22	Haʻipuaʻena		19
Huelo	23	Puohokamoa		20
Huelo	24	Wahinepeʻe		21

Huelo	25	**Alo**	Combined with Waikamoi below as a tributary	
Huelo	26	Waikamoi	Referenced as “Waikamoi (Alo tributary)” per D&O	22
Huelo	27	Kōlea		23
Huelo	28	Punaluʻu		24
Huelo	29	Kaʻaiea		25
Huelo	30	ʻOʻopuola	Referenced as “ʻOʻopuola (Makanali tributary)” per D&O	26
Huelo	31	Puehu		27
Huelo	32	Nailiilihaele	Nāʻiliʻilihaele (diacritical markings added)	28
Huelo	33	Kailua/Ohanui		29
Huelo	34	**Hanauana**	Referenced as “Hanahana (Ohanui tributary)” per D&O.	30
Huelo	35	Hoalua		31
Huelo	36	**Pualoa/Hanehoi**	Referenced as “Hanehoi (Huelo (also known as Puolua) tributary” per D&O	32
Huelo	37	Waipiʻo		33
Huelo	38	Mokupapa		34
Huelo	39	**Hoʻolawa-Liʻili/Hoʻolawa-Nui**	Referenced as “Hoʻolawa (Hoʻolawa ʻili and Hoʻolawa nui tributaries)” per D&O	35
Huelo	40	Honopou	Referenced as “Honopou (Puniawa tributary)” per D&O	36

IIFS D&O Table

Table 1-2 in the EISPN also indicated which of the listed streams were subject to the IIFS. The Table 3 below indicates which of the 36 streams are subject to the IIFS and also shows what the D&O requires relative to its Restoration, Median Base Flow and the Location for the IIFS (combination of what is listed in the Findings of Fact, item 58 (page 17) and D&O item h (page 268).

Table 3: License Area streams subject to IIFS with type, amount and locations of IIFS flow restoration.

Streams in the License Area						
License Area	**Stream Number**	**Stream Name**	**Subject to IIFS**	**Restoration Status**	**Median Base Flow at IIFS (cfs)**	**IIFS Location**
Nāhiku License Area	1	Makapipi	Yes	Full	1.3	Above Hana Highway
	2	Hanawī	Yes	Connectivity	4.6	Below Hana Highway
	3	Kapāʻula	Yes	Connectivity	2.8	On Diversion at Koolau Ditch
Keʻanae License Area	4	Waiaaka	Yes	None	0.77	Above Hana Highway
	5	Paʻakea	Yes	Connectivity	0.9	At Hana Highway

	6	Puakea	No	None	N/A	N/A
	7	Waiohue	Yes	Full	5	At Hana Highway
	8	Kopiliʻula	Yes	Limited	H90 (64% of the Median Base Flow) (For Habitat Restoration)	Below Hana Highway
	8A	Puaakaʻa Tributary	Yes	Connectivity	1.1	Above Hana Highway
	9	East Wailuāiki	Yes	Limited	H90 (64% of the Median Base Flow) (For Habitat Restoration)	At Hana Highway
	10	West Wailuāiki	Yes	Full	6	Above Hana Highway
	11	Wailuānui (Waikani Waterfall)	Yes	Full	6.1	At Hana Highway
	12	Kualani (or Hāmau) (Below Ditch System)	Yes	N/A (Never Diverted)	N/A	N/A
	13	Waiokamilo	Yes	Full	3.9	Below Diversion at Koolau Ditch
	14	ʻŌhiʻa (or Waianu) (Below Ditch System)	Yes	N/A (Never Diverted)	4.7	N/A
	15	Palauhulu (Hauoli Wahine and Kano Tributaries)	Yes	Full	11	Above Hana Highway
	16	Piʻinaau	Yes	Full	14	Above Hana Highway
Honomanū License Area	17	Nuaʻailua	Yes	Connectivity	0.28	TBD
	18	Honomanū	Yes	Limited	H90 (64% of the Median Base Flow) (For Habitat Restoration)	Above Hana Highway
	19	Punalaʻu (Kōlea and Ulunui Tributaries)	Yes	Limited	H90 (64% of the Median Base Flow) (For Habitat Restoration)	Above Hana Highway
	20	Haʻipuaʻena	Yes	Connectivity	4.9	Below Hana Highway
Huelo License Area	21	Puohokamoa	Yes	Connectivity	8.4	Below Hana Highway
	22	Wahinepeʻe	Yes	None	0.9	Above Hana

						Highway
	23	Waikamoi (Alo Tributary)	Yes	Limited	H90 (64% of the Median Base Flow) (For Habitat Restoration)	Above Hana Highway
	24	Kōlea	No	None	N/A	N/A
	25	Punalu‘u	No	None	N/A	N/A
	26	Ka‘aiea	No	None	N/A	N/A
	27	‘O‘opuola (Makanali Tributary)	No	None	N/A	N/A
	28	Puehu	No	None	N/A	N/A
	29	Nā‘ili‘ilihaele	No	None	N/A	N/A
	30	Kailua	No	None	N/A	N/A
	31	Hanahana (Ohanui Tributary – also known as Hanawana and Hanauna)	No	None	N/A	N/A
	32	Hoalua	No	None	N/A	N/A
	33	Hanehoi	Yes	Full	2.54	Upstream of Lowrie Ditch
	33A	Huelo (also known as Puolua) Tributary	Yes	Full	1.47	(Downstream of Haiku Ditch at Huelo)
	34	Waipi‘o	No	None	N/A	N/A
	35	Mokupapa	No	None	N/A	N/A
	36	Ho‘olawa (Ho‘olawa ili and Ho‘olawa nui Tributaries)	No	None	N/A	N/A
	37	Honopou (Puniawa Tributary)	Yes	Full	6.5	Below Hana Highway

*Some of these streams may be identified by other names. The listed names are based on the June 20, 2018 CWRM D&O identified by CWRM and the State Office of Planning's GIS data
*H_{90} is 64% of the median base flow at that stream. These streams are for habitat restoration
*cfs – Cubic Feet per Second, the IIFS numeric flow rate at the IIFS location.
* Diacritical marks (shown in table) will not be used in report due to difficult with inclusion in modeling and analysis software and electronic distribution of the report.

While the HSHEP model follows the naming and numbering conventions, several additional changes were made to the stream list. The changes were as follows:

Watershed 11: Kualani Stream and Watershed 13: Ohia Stream have Habitat Units set to 0 as these streams were not diverted by the EMI Aqueduct System. In reality, they may have some habitat units, but the habitat units will not vary under any scenario as they are not diverted, so they were excluded from analysis. The use of 0 allows them to be included in the tables but not influence total habitat units associated with the diversion scenarios. Habitat Units could be calculated for these streams, but since these streams were unrelated to stream diversions it was uninformative to do so.

Watershed 14: Palauhulu is included within Watershed 15: Piinaau Stream. Palauhulu is a tributary of Piinaau Stream. The HSHEP model defines a stream and its watershed to have a single outlet to the ocean. While internal stream system calculations can be determined for any tributary within the model, both Piinaau Stream and Palauhulu tributary were classified as Full flow Restoration streams so combining or splitting the results would not change any of the total values in the different scenarios. Thus, only Watershed 15: Piinaau Stream was included in the results.

For the East Maui HSHEP model, we delineated all watersheds (full-stream watershed) (Figure 12) and basins (sub-watershed upstream of a model node) in the East Maui region from Makapipi Stream to Honopou Stream. This resulted in 33 watersheds (coded 1 to 36 without Kualani and Ohia streams and with Palauhulu combined with Piinaau Stream) and each watershed and basin were given a unique Identification Number and its position within each stream network defined. Network position defines which other basins are upstream and downstream of each individual basin. The network position allows the accumulation of basin attributes (water, habitat, etc.) in an upstream or downstream direction. The model nodes were major or minor stream diversions associated with EMI Aqueduct System, sinks or springs, and stream mouths.

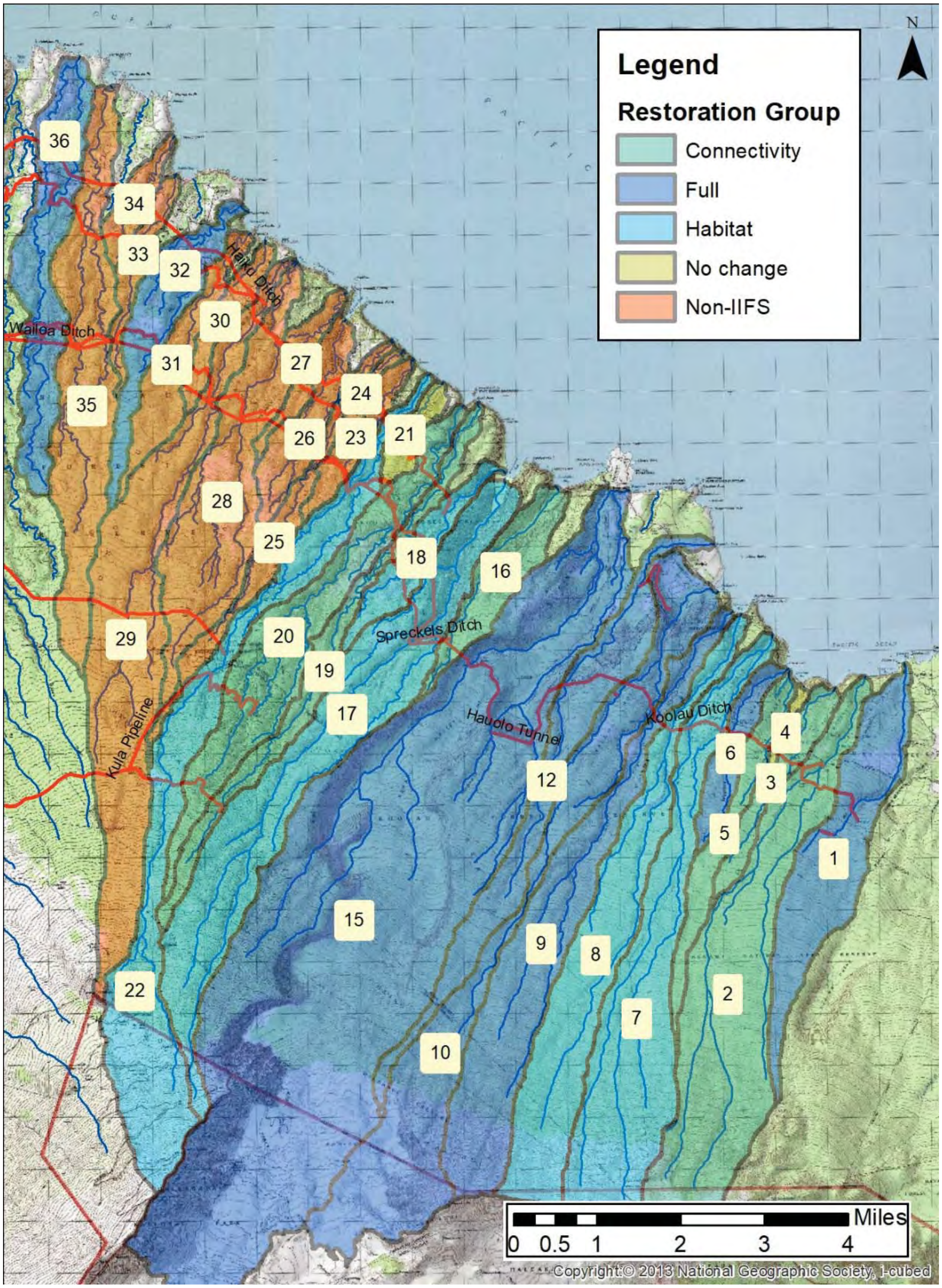


Figure 12: Watersheds within the East Maui HSHEP model. Watersheds are polygons outlined with gray line, numbers correspond to stream ID numbers in License Area stream table, blue lines are streams, red line are diversion ditches and colored refer to IIFS flow restoration status.

DEFINING BASELINE CONDITIONS

A fundamental consideration for developing the HSHEP model for East Maui was the quantification of outer boundary conditions. In the broadest sense, the upper boundary for the model was considered natural undiverted flow throughout the system. This was not necessarily a management scenario, but rather a maximum habitat bounding condition in which management options cannot improve instream habitat for stream species. The lower boundary was full diversion as existed under sugar cultivation which was the prevailing conditions for over 100 years. Two areas of information were needed to estimate the amount of stream habitat present under the boundary conditions: (1) the distribution of suitable habitat and (2) the amount of water in each stream segment. The distribution of suitable habitat came from the HSHEP model which considers watershed and reach characteristics that define the extent of habitat within a stream. The amount of water in each stream segment helps define the size of the stream which influences the amount of habitat.

While habitat and water quantity are all that was needed to determine upper and lower boundary conditions, to effectively model management scenarios additional information associated with the diversion locations was required. Table 4 shows survey dates and streams and Appendix 1 contains the specific results of field surveys completed in proximity of 35 diversions in the East Maui ditch system. We combined the survey information, diversion pictures, and diversion registration information, to create an assessment of all the diversions in the East Maui system with respect to their impact to habitat, entrainment and passage for the amphidromous stream animals. The diversions, springs, sinks, and stream mouths were represented by the nodes in the HSHEP model. Each node was linked to a table determining the condition and its effects at that location. For the baseline condition, all diversion nodes were set to no impact (no water diversion and no habitat, entrainment, or passage effect). The following sections more fully describe the habitat, water quantity and diversion results.

Table 4: Date and Location of field surveys to support the HSHEP modeling of the East Maui Streams. Full results can be found in Appendix 1.

Date	Location	Description
10/10/17	Kailua	Site Survey
10/10/17	Kailua	Site Survey
10/11/17	Waikamoi	Site Survey
10/11/17	Kolea	Site Survey
10/12/17	Makapipi	Site Survey
10/12/17	Hanawi	Site Survey
10/12/17	Hanawi	Site Survey

10/14/17	W. Kopiliula	Site Survey
10/18/17	Waiohue	Site Survey
10/18/17	E.Kopiliula	Site Survey
10/19/17	Banana Intake	Site Survey
10/19/17	E. Honomanu	Site Survey
10/19/17	Honomanu	Site Survey
10/19/17	W. Honomanu	Site Survey
10/19/17	Ulinui	Site Survey
10/19/17	Kolea	Site Survey
10/20/17	Alo	Site Survey
10/20/17	Waikamoi	Site Survey
10/20/17	Alo	Site Survey
10/22/17	Kaaie	Site Survey
10/22/17	Makanali	Site Survey
10/22/17	Oopuola	Site Survey
10/22/17	Hoolawa	Site Survey
10/22/17	Nailiilihaele	Site Survey
10/22/17	Nailiilihaele	Site Survey
10/23/17	Puohokamoa @ Koolau	Site Survey
10/23/17	E. Puohokamoa	Site Survey
10/23/17	W. Puohokamoa	Site Survey
10/23/17	Puohokamoa @ Spreckles	Site Survey
10/23/17	Waikamoi	Site Survey
10/27/17	Paakea	Site Survey
10/27/17	Puakea	Site Survey
10/27/17	Piinaau	Site Survey
10/30/17	Kapaula	Site Survey

10/30/17	Kapaula	Site Survey

HABITAT QUANTIFICATION

The multi-spatial assessment of instream habitat for native amphidromous species used base data, modeling processes, and suitability criteria as close as possible to the information reported in:

Parham, J.E., G.R. Higashi, R.T. Nishimoto, S. Hau, D.G.K. Kuamo'o, L.K. Nishiura, T.S. Sakihara, T.E. Shimoda and T.T. Shindo. 2009. The Use of Hawaiian Stream Habitat Evaluation Procedure to Provide Biological Resource Assessment in Support of Instream Flow Standards for East Maui Streams. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 104 p.

The majority of the habitat quantification in this report was the same as the habitat quantification for the prior HSHEP model created in conjunction with the Division of Aquatic Resources biologists. Differences between this 2018 East Maui HSHEP model and the past 2009 East Maui HSHEP model primarily were:

1. Greater Area of Coverage: The 2018 East Maui HSHEP model reported here covered a wider area with a larger number of streams,
2. Larger Number of Diversions: The 2018 East Maui HSHEP model included many more diversions including minor diversions which were not in the 2009 HSHEP model,
3. Larger Number of Basins: The 2018 East Maui HSHEP model included more basins as each diversion requires its own upstream basin.
4. Better Inclusion of Natural Springs and Sinks: The 2018 East Maui HSHEP model included specific locations of springs and sinks with positive or negative impact directly accounted for in the model. The 2009 model did not address springs or sinks except by noting their presence and potential impact on the results.
5. Different estimate of stream discharge: This is likely the largest difference between the two models. The 2009 East Maui HSHEP model addressed major diversion on the main channel only and USGS had published estimates for these locations. The 2018 East Maui HSHEP model used modified regression equations to account for discharge at the many ungaged sites (see next section). These discharge estimates are likely proportionally consistent across the study area, but they may not be as accurate due to the use of the regression equations for basins smaller than developed on and due to use over a wider geographic area.
6. Habitat Units more proportional to stream size: The 2009 East Maui HSHEP model calculated habitat units as a linear measurement and reported it in total meters of habitat units. The 2018 East Maui HSHEP model used the estimates of discharge for each stream segment to provide an area estimate of stream habitat and reported habitat units in square meters. This results in a much more accurate depiction of habitat units within the streams

as large streams are wider and likely hold more habitat than small streams but makes direct comparison of the results incorrect.

As a result, there were differences in the quantification of habitat availability between these two modeling efforts, but it was not primarily the result of different base data or modeling processes but an improvement in estimating habitat units as the modeling is improved over time. The discussed conversion of the HSHEP model from a spreadsheet model to an R programming-based model did not change internal calculations, it only improved the speed and repeatability of the modeling work. Thus, the underlying maps presented in the 2009 East Maui HSHEP report and reproduced here are still valid as a graphic representation of the data (Figure 13 to Figure 20). Appendix 2 shows the breakdown the specific habitat unit quantified for each watershed and all sub-basins for the native amphidromous species.

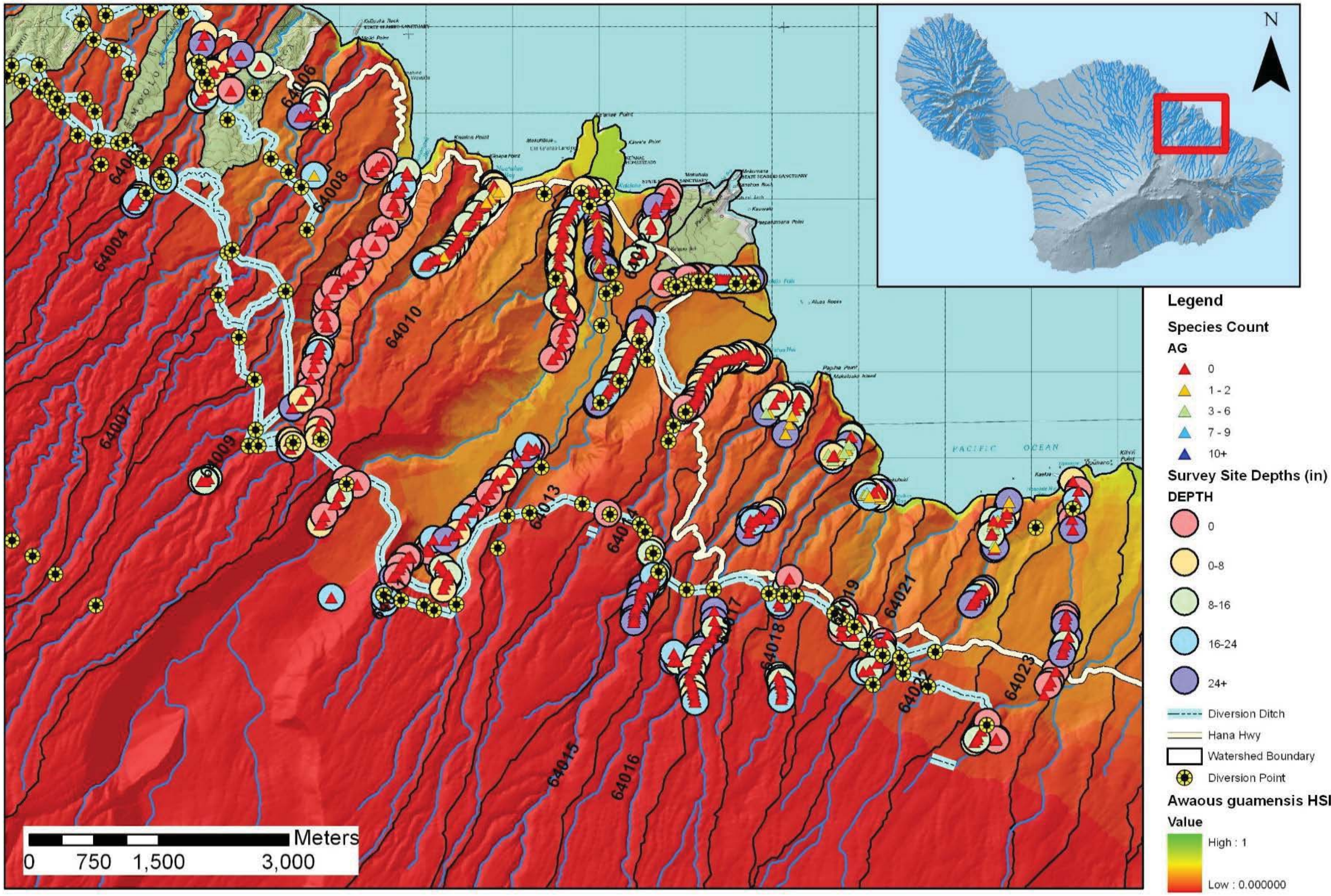


Figure 13: Predicted Habitat Suitability Index (HSI) for Awaous stamenius. Map includes survey site depths and count of Awaous stamenius observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference. (from Parham et al. 2009)

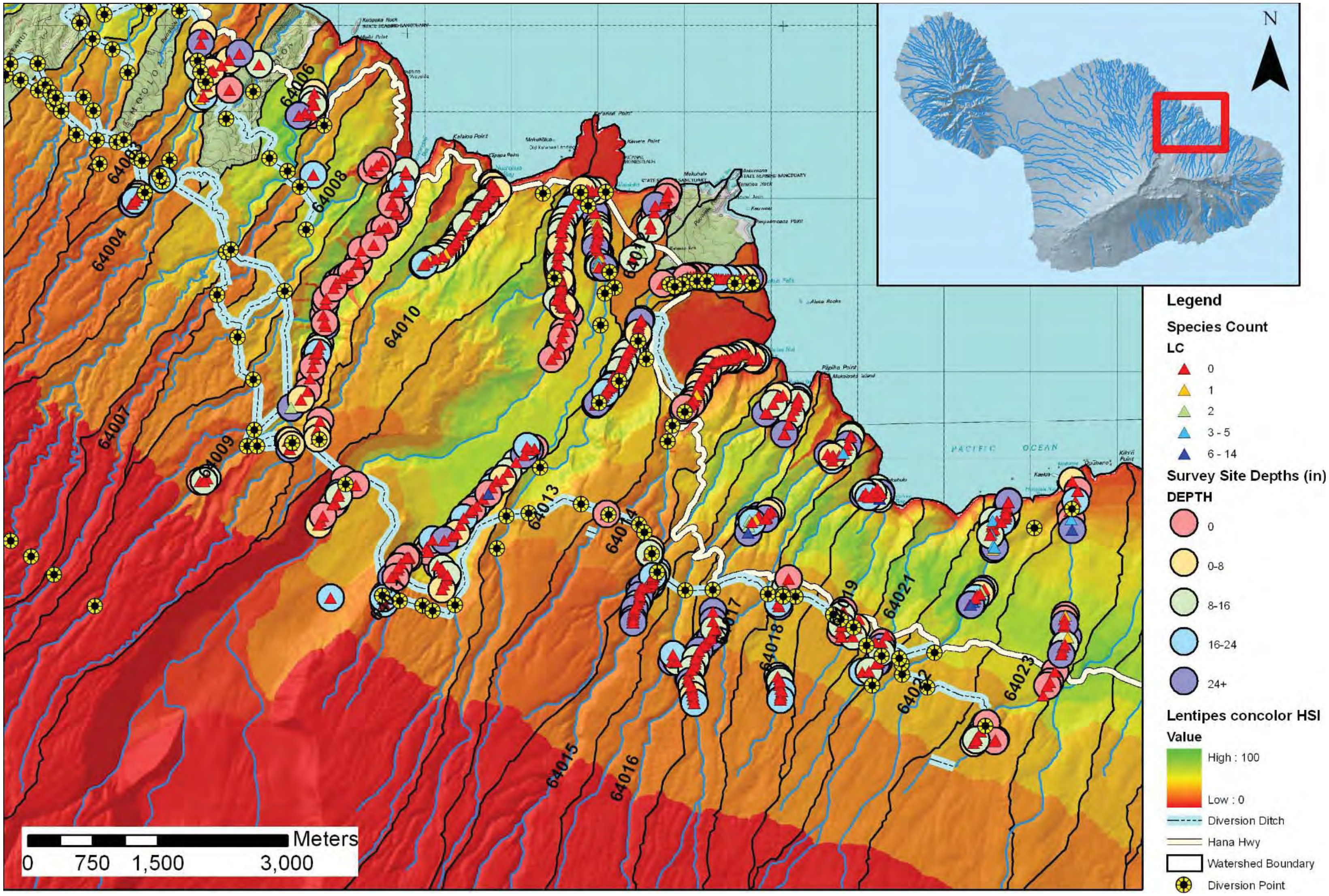


Figure 14: Predicted Habitat Suitability Index (HSI) for *Lentipes concolor*. Map includes survey site depths and count of *Lentipes concolor* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference. (from Parham et al. 2009)

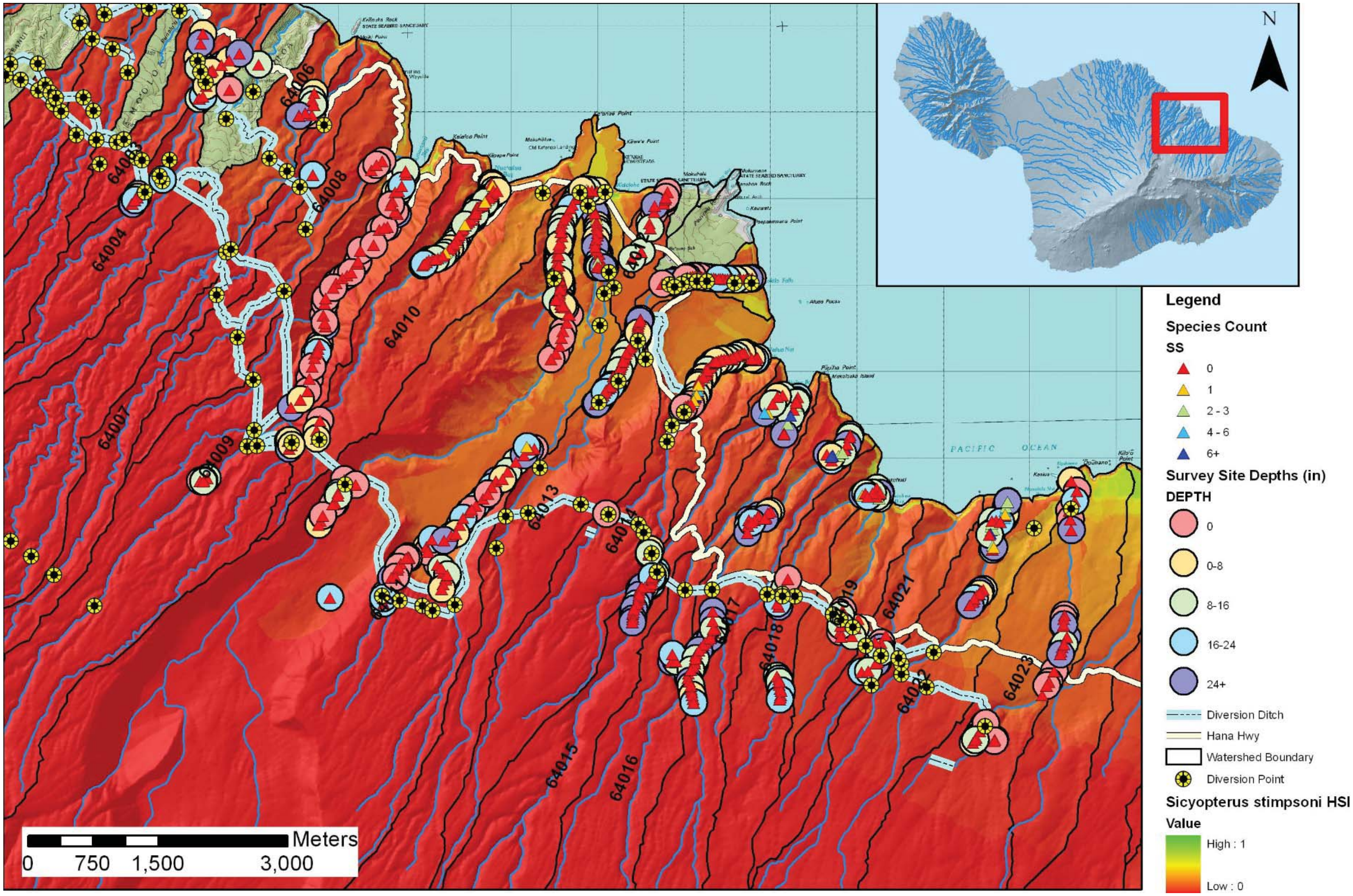


Figure 15: Predicted Habitat Suitability Index (HSI) for *Sicyopterus stimpsoni.* Map includes survey site depths and count of *Sicyopterus stimpsoni* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference. (from Parham et al. 2009)

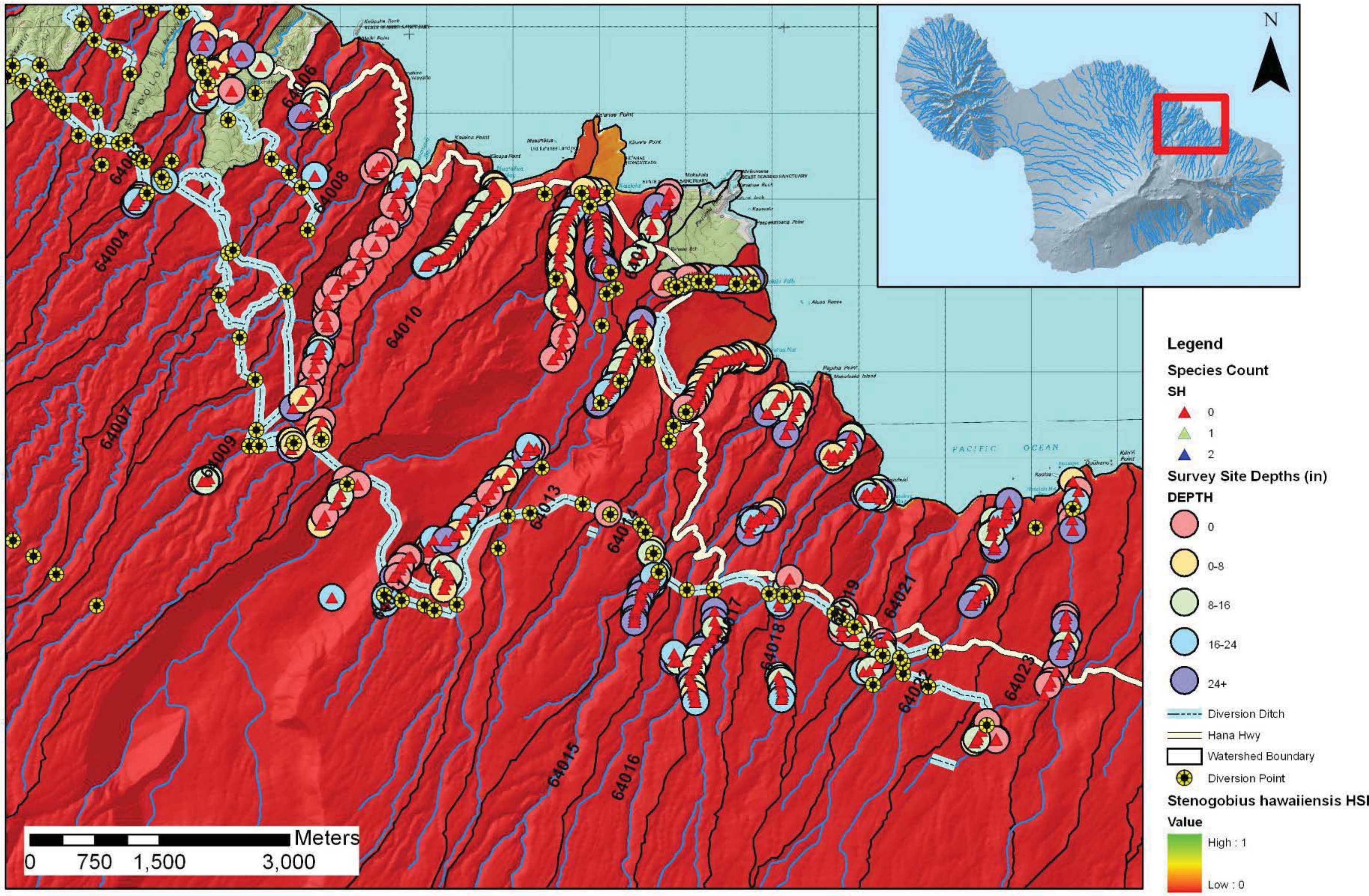


Figure 16: Predicted Habitat Suitability Index (HSI) for *Stenogobius hawaiiensis*. Map includes survey site depths and count of *Stenogobius hawaiiensis* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference. (from Parham et al. 2009)

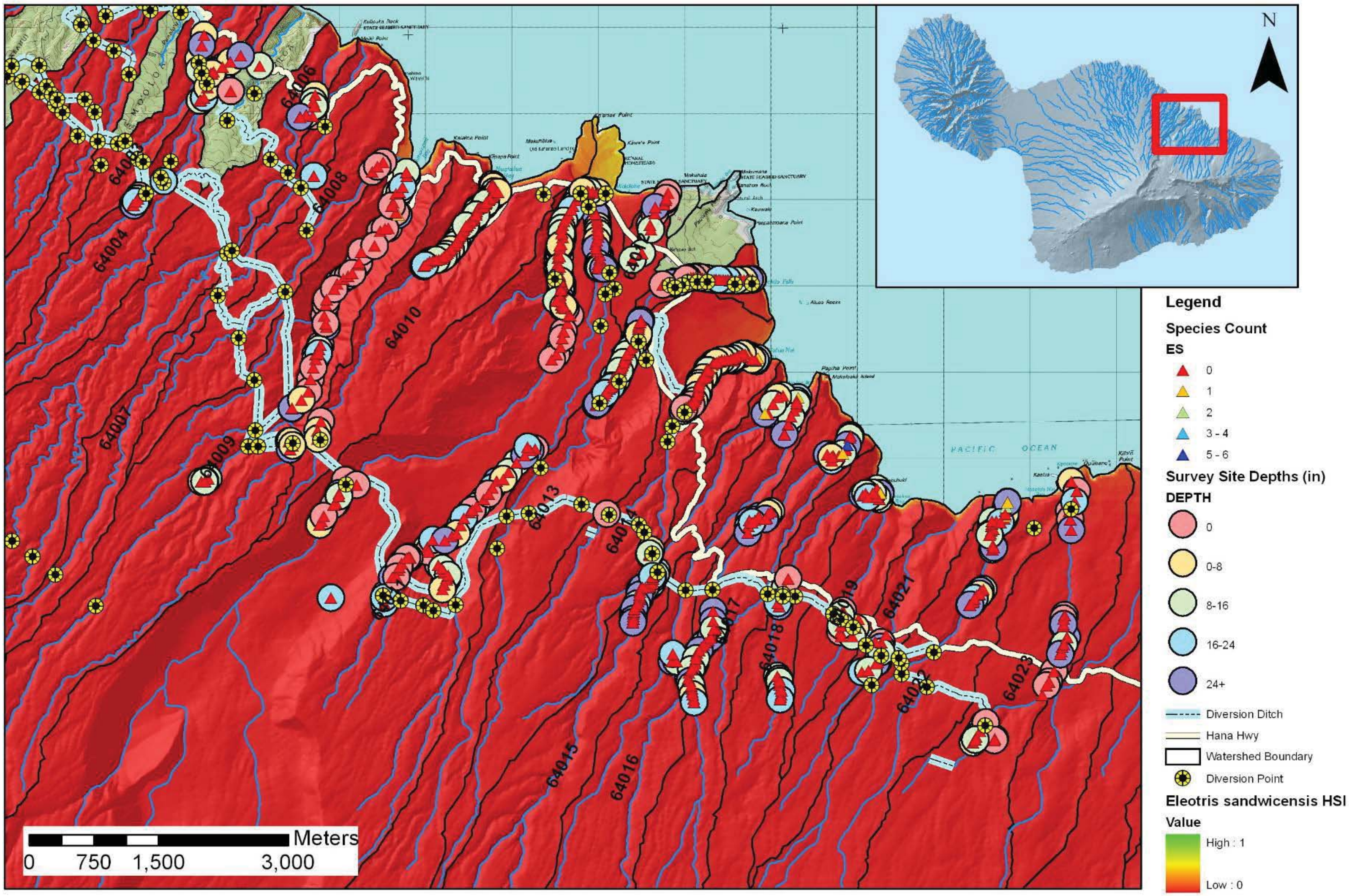


Figure 17: Predicted Habitat Suitability Index (HSI) for *Eleotris sandwicensis*. Map includes survey site depths and count of *Eleotris sandwicensis* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference. (from Parham et al. 2009)

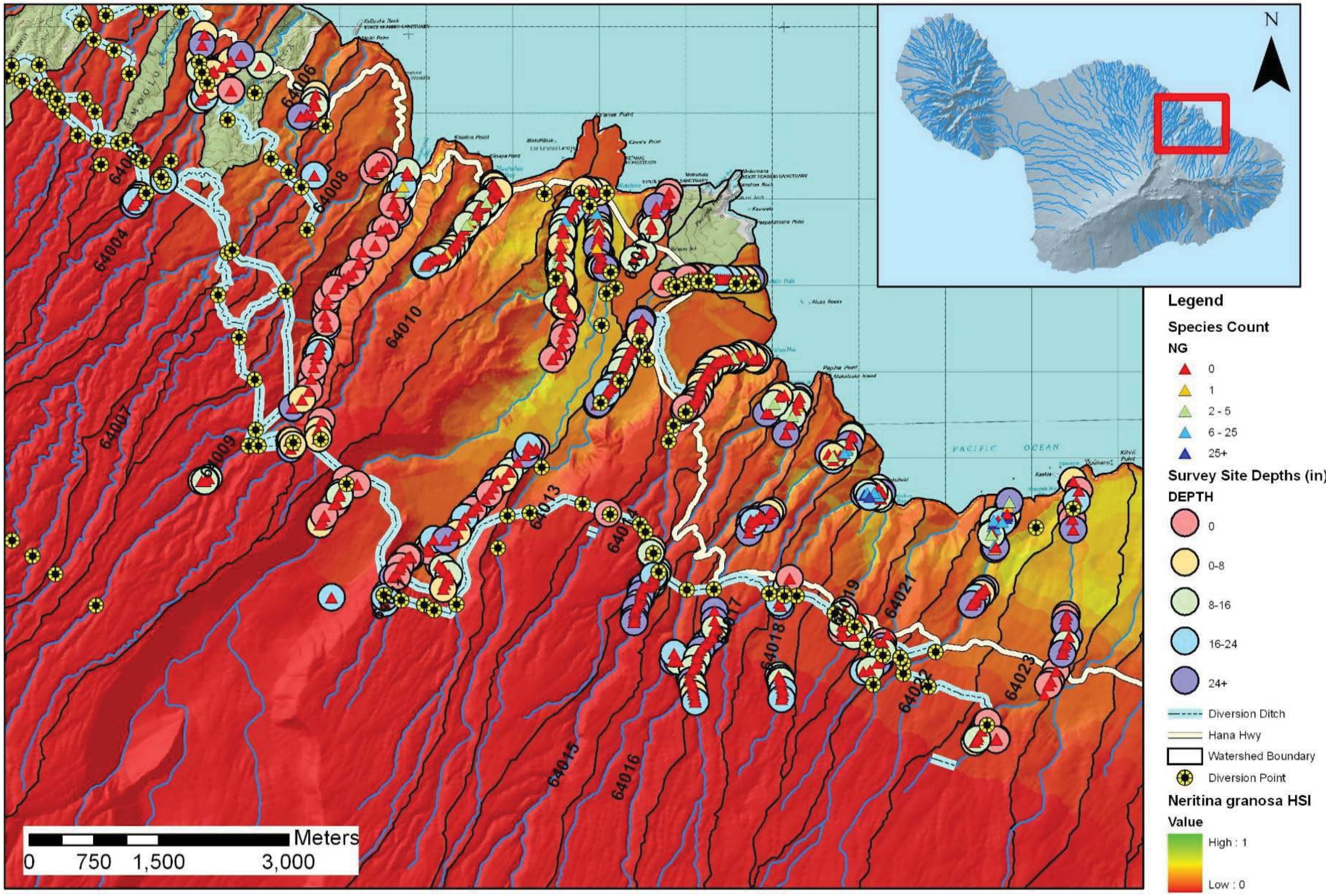


Figure 18: Predicted Habitat Suitability Index (HSI) for *Neritina granosa*. Map includes survey site depths and count of *Neritina granosa* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference. (from Parham et al. 2009)

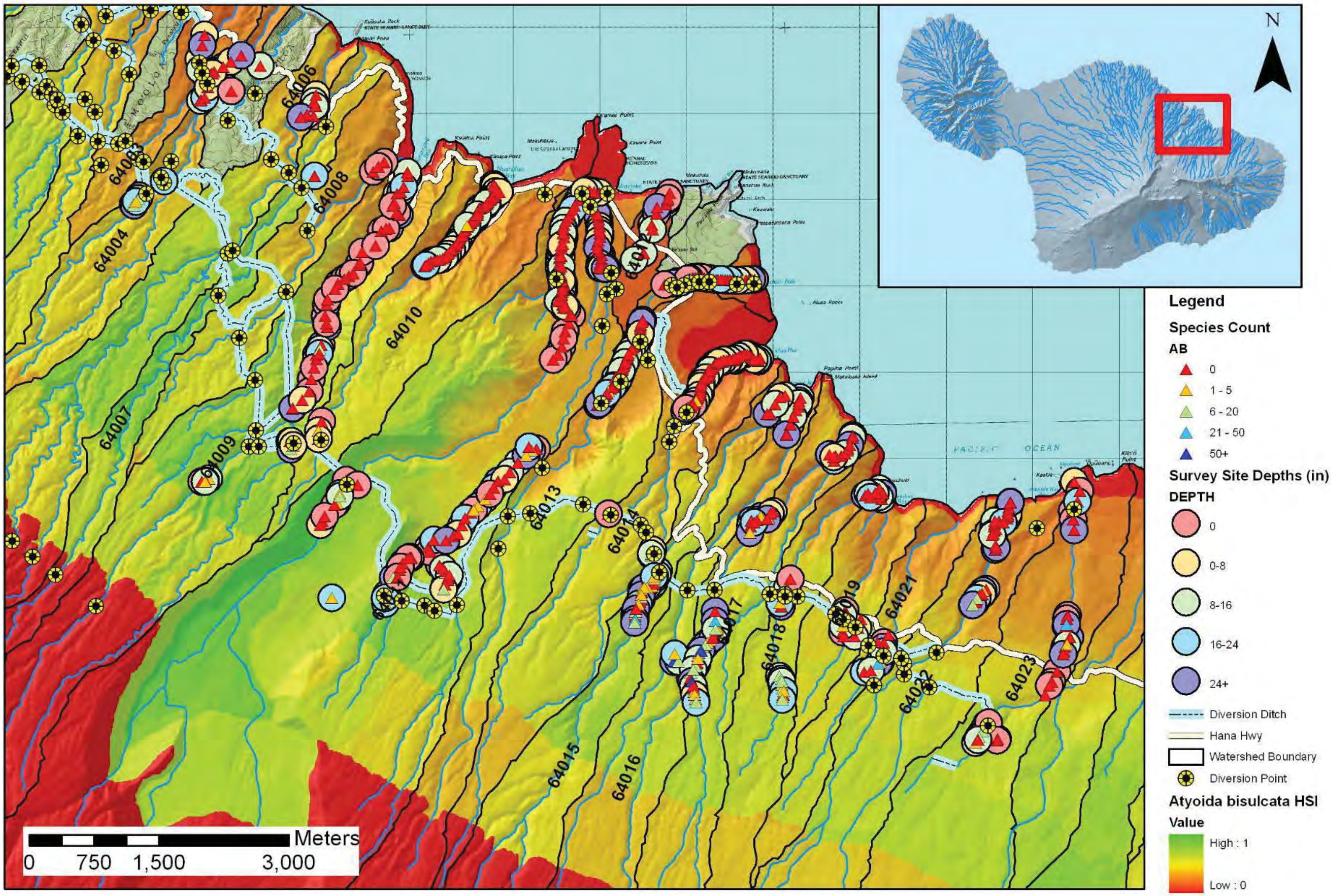


Figure 19: Predicted Habitat Suitability Index (HSI) for *Atyoida bisulcata*. Map includes survey site depths and count of *Atyoida bisulcata* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference. (from Parham et al. 2009)

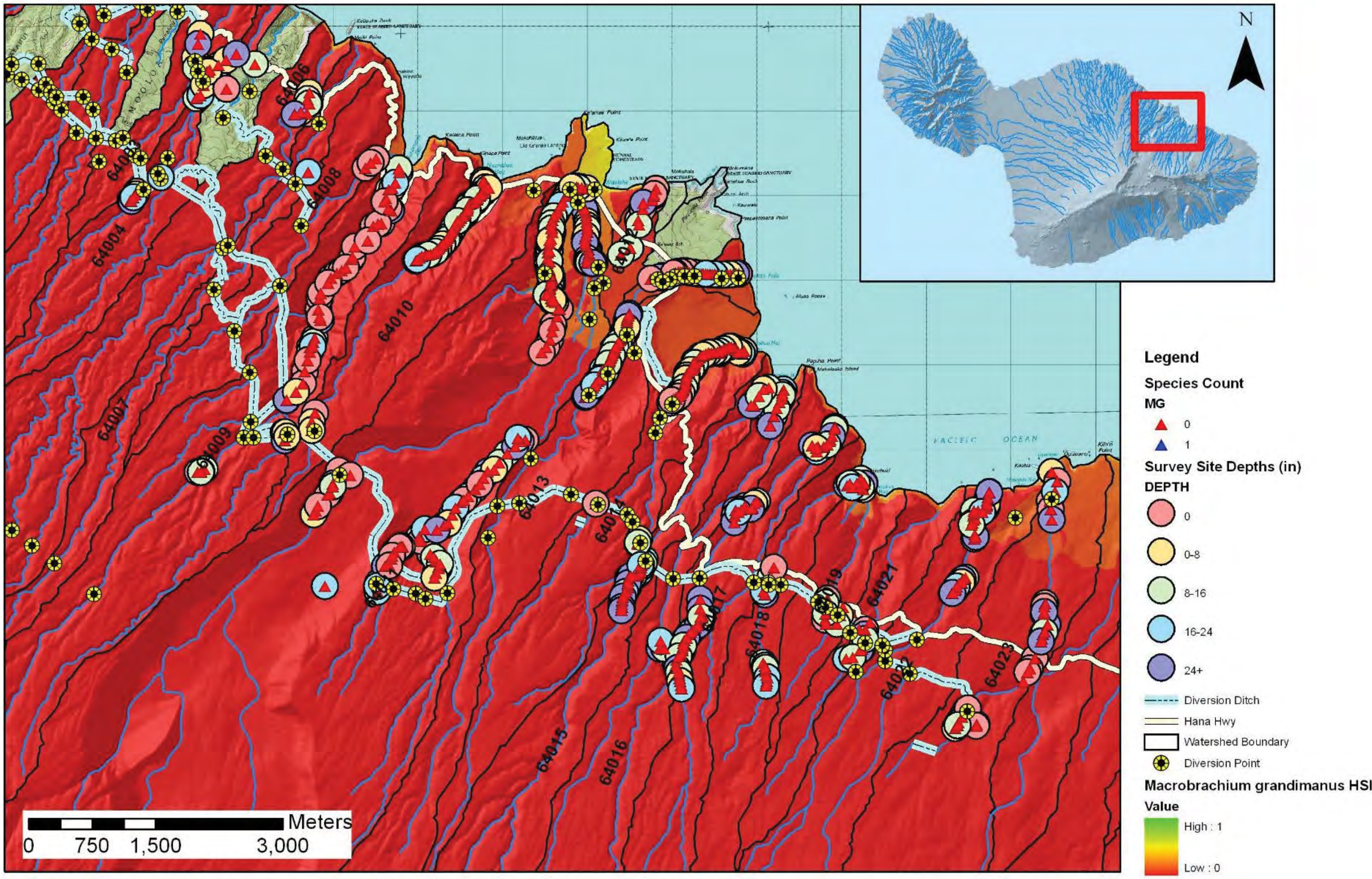


Figure 20: Predicted Habitat Suitability Index (HSI) for *Macrobrachium grandimanus*. Map includes survey site depths and count of *Macrobrachium grandimanus* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference. (from Parham et al. 2009)

BASEFLOW DISCHARGE CALCULATIONS

As part of the overall effort to determine the amount of habitat for different species within a stream segment, we needed a method to estimate baseflow in ungaged locations. The USGS had reported regression equations created from East Maui streams for the specific purpose of estimating discharge at ungaged locations. Unfortunately, the USGS methods and results could not be re-created exactly due to changes in software and differences in the primary data. The software USGS used is no longer compatible with current GIS software and therefore, could not be used to exactly replicate the calculations. Additionally, the stream segments and upstream basins used in this analysis are not the same as those used for the USGS calculations. The USGS segments and upstream basins were focused on USGS gage locations in the East Maui, while this effort focused on diversion locations. To overcome this problem, TRUTTA recalculated the data inputs and results at shared locations and compared it with the reported results. It is important to remember that this calculation was not done to create a new way to determine the amount of water at any location, but merely as a way to proportionally determine the amount of water coming from ungaged or unreported areas so that the amount of habitat was linked with an estimate of stream discharge at each location.

Twenty-nine sites where the HSHEP and the USGS measurement locations closely matched. At these locations, the rainfall, maximum basin elevation, and basin elongation ratio were recorded from the USGS report and the values were calculated using GIS software (ArcMap 10.2) from the new data set (Figure 21: Map with Rainfall, elevation, and watershed outline (basin elongation ratio) with respect to the East Maui watersheds.). From this new comparative data, TRUTTA recalculated the expected discharge statistic based on the reported regression equations for each location using both the USGS data and our data. This first comparison appeared reasonable, but when these relationships were applied to all the basins in the new East Maui HSHEP model, many of the results for very small basins appeared inaccurate. The original USGS equations were replotted against a range of possible values and highly variable results were observed at the low end of maximum basin elevation and basin elongation ratio equations (Figure 22). This is likely because the USGS data had no small values in their data set and thus the equation was valid only over the range of observed values.

Range cutoffs were placed to eliminate these excessively large values in the extreme conditions and recalculated the discharge relationships between the two data sets. The results appeared consistent for the internal measurements of rainfall, maximum basin elevation and basin elongation ratio as well as the discharge predictions at similar locations (Figure 23). This approach allowed discharge for all of the basins within the HSHEP model to be predicted and have the results scaled appropriately with prior USGS predictions. It also allowed estimates of percent diversion to proportionally impact the overall remaining discharge at all locations downstream as additional stream segments converged and added flow to the stream.

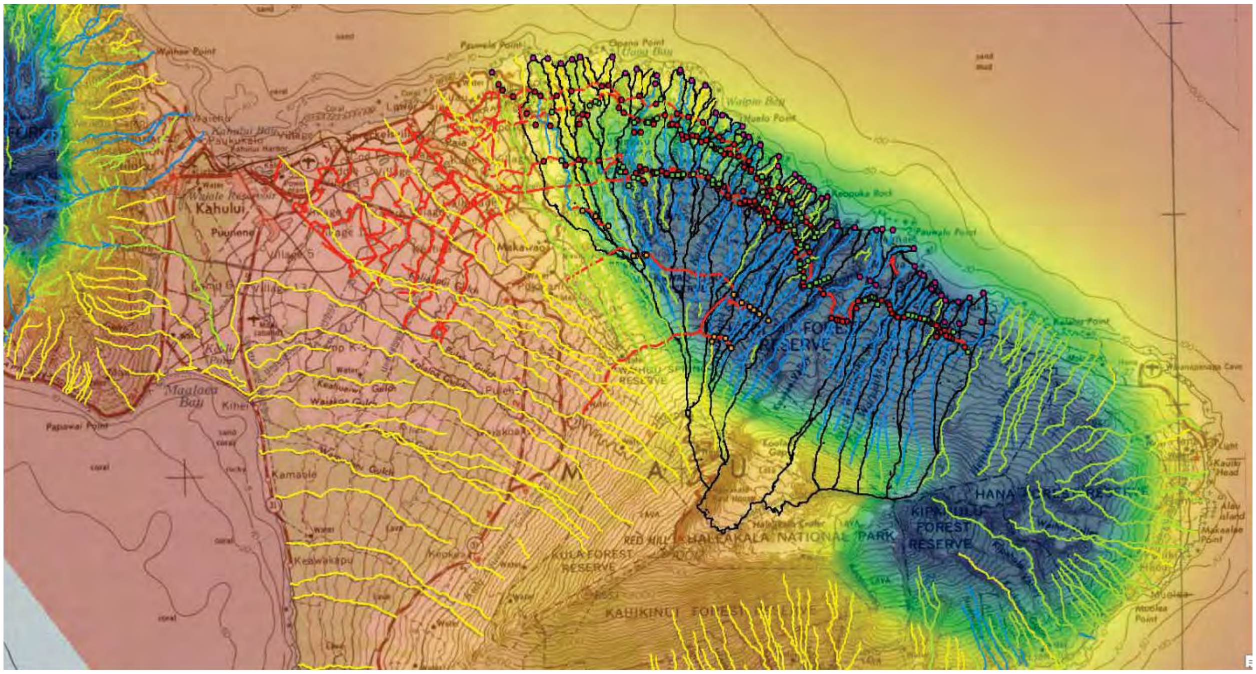


Figure 21: Map with Rainfall, elevation, and watershed outline (basin elongation ratio) with respect to the East Maui watersheds.

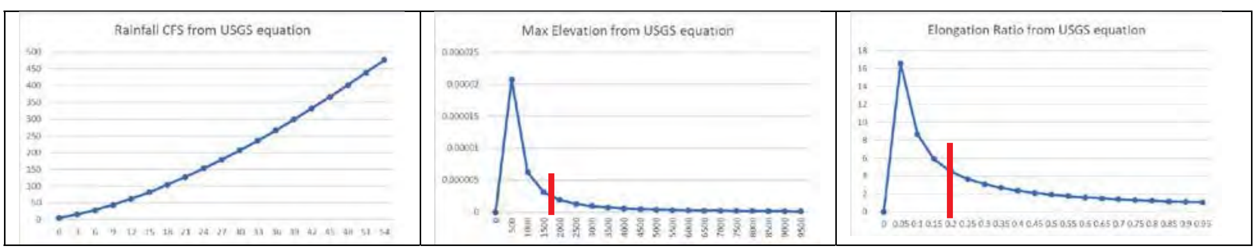
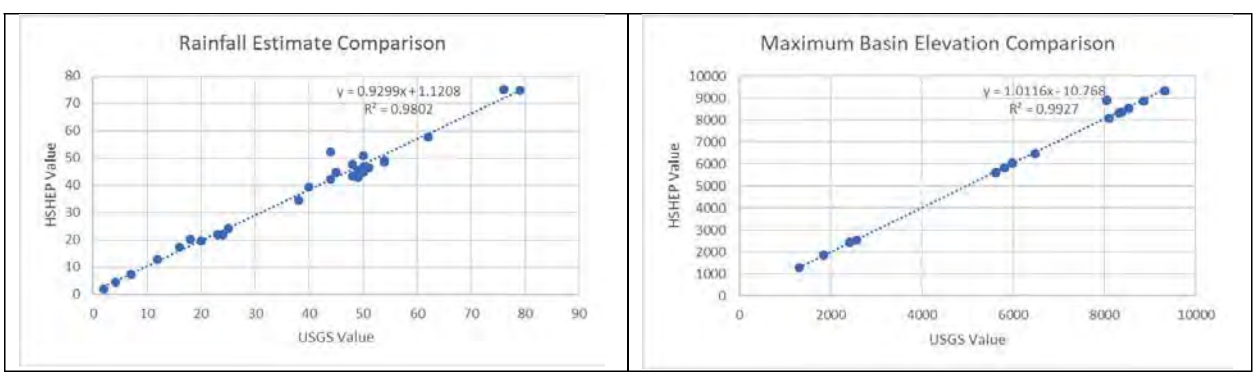


Figure 22: Range of values for variables in USGS discharge regression equation. Cutoff shown in red.



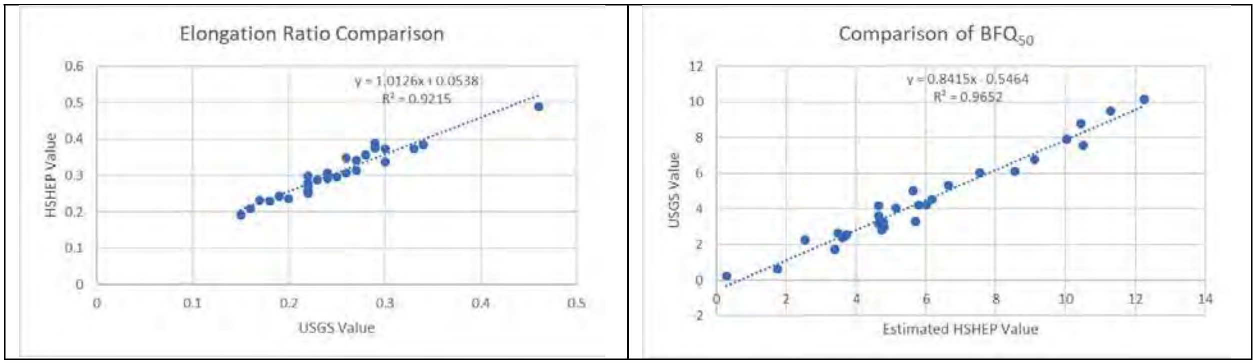


Figure 23: Comparative relationships between HSHEP modeling prediction and USGS regression values for Rainfall, Maximum Basin Elevation, Basin Elongation Ratio and Discharge.

NODE DESCRIPTIONS

The nodes in the HSHEP model represent points of interest to help better answer the modeling question. For the East Maui HSHEP model most of the nodes are the major or minor diversions associated with the EMI Aqueduct System. There are also nodes at the stream mouth of each stream, major splits between mainstem and tributary streams, or at springs or sinks. Each node has a similar set of attributes associated with it and these include an ID, Name, Type, ditch associated with it, proportion water diverted, proportion water passing, upstream and downstream entrainment, up and downstream barrier, up and downstream habitat impact, and a change in discharge (for springs or sinks). Not all attributes are relevant to all node types and where there is no interaction the node value was set to zero effect. Appendix 2 contains the node and basin values for each of the scenario descriptions below.

SCENARIO DESCRIPTIONS

1. Natural Condition: This was the baseline comparison scenario in which all diversions were modeled as closed with no water diversion and no impact on passage or entrainment of animals. This was the maximum available habitat units predicted.

2. Full Diversion: All diversions in this scenario were modeled as fully open or diverting 100% of available low flows. The low flows, roughly analogous to the stream's baseflow, are critical to protecting instream habitat for stream species. The diversions and aqueduct system were built to capture 100% of normal low flow plus some smaller amount of storm runoff. Hawaiian streams are "flashy" where discharge rises quickly in response to rainfall and then quickly falls back to low flow conditions. When low flow conditions persist and overall diversion amounts do not exceed the conveyance capacity of the aqueduct, the streams can be dewatered below the diversions resulting in negative impacts on species habitat and passage. This

scenario was intended to represent the diversion conditions found during sugar cane production.

3. 2018 IIFS: This scenario represented the flow conditions as described in the 2018 Interim Instream Flow Standard (IIFS) which included 24 streams and mandated restoration of flows in all but three streams. Four main types of flow restoration were mandated, including: Full-flow restoration, Habitat-flow restoration, Connectivity-flow restoration, and No-flow restoration. The diversion amount was estimated as available flow after compliance with the 2018 IIFS.

4. No action alternative or 30% remaining flow diversion: This scenario represented the long-standing agreement that “government owned waters” from the License Area amounted to 70% of streamflow, and the remaining 30% of the streamflow emanated from private/A&B/EMI lands. Thus, the No-Action alternative is the diversion of 30% of water available at the Honopou Stream boundary after compliance with the IIFS. This No-Action description is not directly translatable into the HSHEP model as the model requires specific diversion conditions at each diversion not an aggregate amount from a group of diversions. Therefore, this scenario assumed that 30% of remaining low flow discharge was diverted at each individual diversion after complying with the IIFS.

Under all of these scenarios, several specifics within the 2018 IIFS are applied to the HSHEP modeling rules. These included:

III-g: The IIFS are the estimated 64% of median base flows (BFQ_{50}), also known as (H_{90}) flows, for stream restoration, and the numbers are only estimates, to eventually be confirmed by actual flows from which the H_{90} can be established.

III-i: It is intended that diversion structures only need to be modified to the degree necessary to accomplish the amended IIFS and to allow for passage of stream biota, if needed.

III-j: This Order does not require that every diversion on every tributary be removed or modified, the Commission is only looking at modifications to main stem and major diversions to accomplish the amended IIFS set forth above. The Commission also recognizes that it is not the purpose of this proceeding to determine how the diversions will be modified. That issue will be before the Commission in a subsequent process.

Therefore, only major diversion conditions were modified in the HSHEP model and no specific passage or entrainment modifications were applied except of the effects provided by the increased water passing downstream at the major diversions. Any action or modification of the diversion to decrease entrainment would increase the total restored habitat units without any additional water released to the stream.

DISCUSSION

The HSHEP model provided the ability to look at and modify characteristics of each diversion and quantify instream habitat for the native amphidromous stream animals, native damselflies and introduced mosquitoes upstream and downstream of the diversions. Appendix 3 documents the results for the four scenarios analyzed in this report: natural flow, full diversion, 2018 IIFS diversion, and the 30% remaining flow diversion. All four of the scenarios were created for the IIFS streams and only the three scenarios (natural flow, full diversion, and the 30% remaining flow diversion) were created for the non-IIFS streams in the License Area as there was no IIFS mandated for these streams. The approach allows each stream, ditch system, lease area or other groupings to be analyzed systematically. After studying the results of various potential groupings, we found the most appropriate group to be those created by the 2018 IIFS decision. These groups were Full-Flow Restoration, Habitat-Flow Restoration, Connectivity-Flow Restoration, No-Flow Restoration and Non-IIFS Streams. A discussion of each group follows.

FULL-FLOW RESTORATION

The lease-area streams designated as Full-Flow Restoration streams in the 2018 IIFS were: Makapipi, Waiohue, West Wailuaiki, Wailuanui, Waiokamilo, Piinaau (and its tributary Palauhulu), Hanahoi (Huelo/Puolua), and Honopou Streams.

The full-flow restoration streams are some of the largest streams, with the majority of the lower and stream reaches found in this area. The primary reason for full-flow restoration was not the improvement of instream habitat for stream animals, but rather the downstream passage of water for customary and traditional uses (mostly taro cultivation) by Hawaiian communities. While not the primary reason, full restoration of flow does provide instream habitat benefits for the native amphidromous stream animals. The results from the HSHEP model calculated 706,507 m^2 of habitat units for all native amphidromous species within these eight streams. Remaining habitat units for all species were 74.8% of the total even during full diversion within the streams and 96.7% was estimated to exist under the 2018 IIFS with a few percentages more (98.4%) under the 30% remaining flow diversion scenario.

This group included Piinaau Stream and estimates for this stream were the most difficult to create. Determining flow in the segments of this very large stream was likely inaccurate as the rainfall runoff to discharge equations used (based on prior East Maui studies by USGS) were known to be poor fits for the stream. It is very likely discharge was overestimated and therefore habitat was overestimated as well. In one sense this does not matter, as full-flow restoration is planned for the stream, and thus whatever habitat units are available will likely be restored. It may however skew the results as over 356,000 m^2 were predicted in this stream alone. When we excluded Piinaau Stream from the results, the full-diversion flows removed 44.6% of the habitat units from the streams and the 2018 IIFS scenario increased the habitat units restored to 93.5% of. Again, a small increase in habitat units to 96.9% was observed under the 30% remaining flow diversion scenario and this was due to 70% base flow restoration at all minor diversions throughout these watersheds.

A consistent pattern observed throughout East Maui streams held true regarding individual native amphidromous species within the streams. In descending order, *Atyoida bisulcata, Lentipes concolor, Awaous stamenius, Neritina granosa, and Sicyotperus stimpsoni* had the greatest amount of habitat units. These species make up the "climbing" native stream species that can be found upstream of waterfalls. Waterfalls are a common feature in East Maui streams.

For the native damselflies and invasive mosquito, a return to natural flow conditions should improve damselfly habitat and decrease mosquito habitat where these species use instream habitats. The potential beneficiaries were the endangered damselfly, *Megalagrion xanthomelas* and *Megalagrion pacificum*. Small gains in potential suitable habitat units occurred in these streams and restoration of flow to a more natural condition should directly benefit the species. The restoration of baseflow however will likely also improve habitat conditions for a number of introduced predator and competitor species of the native damselflies and thus may not in itself increase damselfly populations.

Makapipi Stream is an example of a full restoration East Maui streams. Makapipi Stream is a steep, narrow perennial stream with extensive upper (33.8%) and headwater (54.4%) reaches and limited lower (0.9%) or estuarine (0.0%) reach habitats (Parham et al. 2008). There was a sink below the Hana Highway that removed an unknown large amount of base flow from the stream (D&O 2018). For the HSHEP model, the sink was modeled to remove 100% of BFQ_{50} and decrease 30% of the passage and entrain 30% of the animals passing the sink location. We could not access the sink location as the terrain was very steep and thus the amount of water, passage and entrainment effects were estimated.

Makapipi Stream was expected to contain substantial amounts of habitat units for the climbing amphidromous stream animals under natural flow conditions with the most habitat for *Atyoida bisulcata* (8,801 m^2) and *Lentipes concolor* (6,441 m^2) in the main diversion (K-1) area (Appendix 3). *Atyoida bisulcata* (68%) and *Lentipes concolor* (45%), showed the largest amounts of lost habitat units under full diversion resulting from the direct loss of habitat from dewatering and passage and entrainment at the diversion site. Closure of the main diversion as mandated in the 2018 IIFS and the elimination of streamflow diversion at the main diversion site was expected to improve habitat units for all species from 56% under full diversion to 89% under the IIFS conditions. Restoration of habitat units did not return to 100% due to a minor diversion decreasing a portion baseflow below the Koolau Ditch. Little gain in habitat units was realized under the 30% flow scenario (90%) when compared to the IIFS scenario (89%) as the minor diversions flow changed but only a small amount with respect to the main channel diversion. While Makapipi and Piinaau Streams were the only streams with the modeled sinks, the general pattern observed in Makapipi Stream still applied to the other streams.

HABITAT-FLOW RESTORATION

The License Area streams designated as Habitat (H_{90}) Flow Restoration streams in the 2018 IIFS were: Kopiliula, East Wailuaiki, Honomanu, Punalau/Kolea, and Waikamoi Streams. This group of streams was mandated to have approximately 64% of the baseflow restored specifically to improve instream habitat for native stream animals. The selection of the streams was appropriate, as all were predicted to have substantial instream habitat by the HSHEP model. A total of 224,192 m^2 of habitat units were expected to be found within this group of five streams.

The general response pattern within the four scenarios was similar to that observed in the full-flow restoration streams. Full diversion eliminated 49.9% of the habitat units naturally occurring in this group of streams. The restoration of 64% of the baseflow increased available habitat units to 77.1% of the naturally available habitat units. Under the 30% remaining flow diversion scenario, the restored habitat was 91.1%. This was to be expected as restoring 70% of the remaining 36% of flow available for diversion results in approximately 90% of the baseflow restored to the streams. At the No Action (30% diversion of available flow) restoration, nearly all instream habitat was restored below major diversions and remaining losses were due to entrainment of animals as they passed the diversion locations.

As with all East Maui streams, the greatest number of habitat units were for *Atyoida bisulcata* and *Lentipes concolor;* the two most upstream native stream species. Additional habitat units may be gained for the native stream species by decreasing entrainment at the diversion locations. The restoration of baseflow (64% of BFQ_{50}) to meet 90% of the available habitat was likely appropriate, yet this still leaves approximately 36% entrainment at each diversion. Any action or modification of the diversion to decrease entrainment would increase the total restored habitat units without any additional water released to the stream.

For the native damselflies, *Megalagrion nesiotes* has been reported upstream of the diversion on East Wailuaiki Stream. The restoration of 64% of baseflow would increase habitat downstream of the diversion which may be suitable for the species. While it is not clear how important the main channel habitat is for the species, the conditions will be far more natural than the highly diverted conditions immediately below the diversion under the full-diversion scenario. The improved baseflow throughout all reaches downstream of the diversions may also improve habitats for the other endangered damselfly species and would decrease standing water habitat within the stream for the mosquito species. The restoration of 64% of baseflow was predicted to decrease the introduced mosquito, *Culex quinquefasiatus*, by 28% of full diversion conditions.

CONNECTIVITY-FLOW RESTORATION

The License Area streams designated as Connectivity-Flow Restoration streams in the 2018 IIFS were: Hanawi, Kapaula, Paakea, Nuaailua, Haipuaena, and Puohokamoa Streams. Within the group of stream designations for connectivity flows, two subgroups were observed. The first group contained spring fed streams, Hanawi and Kapaula, while the second group contained the remaining streams.

The spring-fed streams have had consistent baseflow downstream of the diversion as a result of the spring inputs. Hanawi Stream is noted for its large springs (Big Spring and Hanawi Spring) and Kapaula Stream has Pali Spring adding consistent baseflow to the stream below the Koolau Ditch Diversions. Hanawi has 4 diversions (3 major and 1 minor) on two primary tributaries upstream of the Hana Highway while Kapaula Stream has 4 major diversion with 2 on the main channel. As with many East Maui streams, these streams are very steep and narrow in their upper reaches and with the most habitat units predicted for *Atyoida bisulcata* (Hanawi 39,556 m^2 and Kapaula 8,005 m^2) and *Lentipes concolor* (Hanawi 34,601 m^2 and Kapaula 10,429 m^2). These streams differ from most East Maui streams with its large spring inputs into the lower mile of the stream channel. As a result of the additional baseflow, the streams supported high numbers of native stream animals below the springs (DAR 2009) and had higher amounts of habitat units predicted from the HSHEP modeling for most native streams animals than most East Maui Streams (Appendix 3).

Given the natural spring flows and the extensive habitat created by them downstream of the diversions, Hanawi was expected to have a large amount of total native stream animal habitat units (126,408 m^2) as well as a large percent of the habitat units (69.0%) remaining even during the full-diversion scenario. Kapaula spring inputs were not as large as Hanawi and thus had fewer overall habitat units (25,418 m^2) as well as a similar percentage of the habitat units (67.0%) remaining under the full-diversion scenario The small amount of water returned under the 2018 IIFS scenario for improving stream connectivity slightly increases the percent of total habitat units (Hanawi 69% and Kapaula 68%) as entrainment and loss of habitat below the diversions would still be high in this scenario. Under the 30% scenario, decreases in entrainment and increases in habitat resulting from the 70% baseflow restoration lead to a greater percent of natural habitat units being available to native species (Hanawi 81% and Kapaula 85%). The HSHEP model did not consider potential design improvements to stream diversions to minimize entrainment as these are not mandated under the 2018 IIFS. These stream diversions would benefit from modifications to decreased entrainment as much of the streams have high baseflow and a connectivity flow would have been established below the diversions.

The endangered damselfly populations may benefit slightly from the connectivity flow as it would keep the stream channel wet immediately below the diversions and other stream segments (above the diversions and below the springs) already contain water under most flow conditions. Mosquito populations may decrease slightly as more flowing water and less stagnant water would exist between the diversions and the springs, but the change was small in all scenarios.

The second group of streams within the Connectivity-Flow Restoration group, Paakea, Nuaailua, Haipuaena, and Puohokamoa Streams, were streams without springs or obviously gaining reaches. Paakea, Nuaailua, Haipuaena Streams were relatively small streams in terms of their available instream habitat units for the native amphidromous stream animals. Puohokamoa

Stream, in contrast, was predicted to have large amounts of suitable habitat units for the stream species. Overall within this group of four streams, the HSHEP model results predicted 301,005 m² of habitat units in this stream group of which Full-flow diversion left 30.0% of the habitat remaining. The connectivity flow increased this to 32.0% of available habitat. Approximately 189,000 m² of the 301,005 m² available habitat units are found within Puohokamoa Stream. One difficult aspect with restoring habitat units through flow restoration in Puohokamoa Stream was the multiple levels of diversions on the stream. Puohokamoa Stream has 3 major (Spreckels, Wailoa, and Manuel Luis Ditches) and 5 minor diversions. While flow restoration may improve habitat in the stream, it may be more difficult to achieve given the number of diversions located on this stream.

NO-FLOW RESTORATION

The License Area streams designated as No-Flow Restoration streams in the 2018 IIFS were: Waiaaka, Ohia/Waianu, and Wahinepee Streams. Ohia Stream is undiverted by the EMI Aqueduct System so natural flow conditions already exist. Waiaaka and Wahinepee Streams were considered intermittent in the DAR stream GIS data layer and thus, by definition within the HSHEP model rules, did not contain habitat units for native amphidromous stream animals that would be impacted by baseflow reduction. The habitat for native damselflies or mosquitos would be minimally impacted by diversion on these streams as it is expected that the streams dry up intermittently and the diversions would mainly capture storm flows. The standard of No-Flow Restoration appears appropriate for these streams as instream habitat conditions are likely similar among any flow scenario.

NON-IIFS STREAMS

The non-IIFS streams were located on the western side of the East Maui stream group. This area receives less rain than the streams further east. These streams also have more extensive diversion systems than streams to the east of Piinaau. Most of the non-IIFS stream were diverted at four levels by Wailoa and New Hamakua Ditches at higher elevations and Spreckels, Center, Lowrie or Haiku Ditches at the lower elevations. The more extensive diversion systems were reflected in more low or no flow conditions observed in the field (see Appendix 1) and in the loss of habitat units in the HSHEP model results. Under the Natural Flow Scenario, over 588,000 m^2 of habitat units were predicted for the native amphidromous species, while under the Full Diversion Scenario 88,386 habitat units were predicted to occur. Thus, under the Full Diversion Scenario only 15% of the habitat units remain in this group of streams. The loss of habitat was both from loss of instream habitat to water diversion and to passage and entrainment issues at each diversion. The 30% Diversion Scenario returns the habitat units available to almost 200,000 m^2. Under this scenario, a wetted pathway would exist to the ocean, but there would still be substantial entrainment of larvae in the multiple diversion ditches. Increased restoration of the flow at the lower diversions may be a better practice than partial diversion of flow at all diversions. This strategy would allow diversion of water at higher elevations where less habitat naturally exists and decrease passage and entrainment impacts at lower diversion where more native stream animals will interact with the diversions.

DISCHARGE TO HABITAT

One major addition to the HSHEP model that was created specifically for this application in the East Maui streams was the ability to predict baseflow discharge for any upstream basin within the study area. The modeled predictions were based on the USGS East Maui discharge regression equations. Due to differences in source data and computational processes, the discharge estimates created for the HSHEP model did not yield the exact same answer as those determined by the USGS. Table 1 shows a comparison between the HSHEP discharge value and the nearest USGS discharge value. In total, the HSHEP predicted less total stream discharge (129.5 cfs) than did the USGS predictions (137.5 cfs) for the same set of streams. As noted in the methods section, the HSHEP was used to create discharge predictions at many more locations, for much smaller upstream basins, and for locations much nearer the coast than was used in the creation of the USGS discharge regression equations and thus was likely an overextension of their equations and less accurate as a result. With that said, the intent was to provide a way to proportionally compare stream size, discharge, and instream habitat under different diversion scenarios at many locations where no stream gage data existed and for this application the results appeared highly useful.

Table 5: Comparison of stream discharge values from the HSHEP model and the USGS report. Discharge values are for the stream mouth in the HSHEP model and the lower reach in the USGS report.

Stream	HSHEP (cfs)	USGS (cfs)	% Diff
Hanawi	26.6	26	-2.3
Kapaula	7.1	5.7	-24.6
Waiaaka	0.8	1.1	27.3
Paakea	3	5.5	45.5
Waiohue	3.8	7.5	49.3
Kopiliula	8.2	9.5	13.7
East Wailuaiki	6.3	7.2	12.5
West Wailuaiki	4.9	7.2	31.9
Wailuanui	7	6.1	-14.8
Waiokamilo	5.9	8.7	32.2
Nuaailua	8.9	7.4	-20.3
Honomanu	10.2	9	-13.3
Punalau	3.8	4.5	15.6
Haipuena	6.3	5.5	-14.5
Puohokamoa	10.8	11	1.8
Wahinepee	3.1	1.8	-72.2
Waikamoi	6.2	7	11.4
Hanehoi	6.6	6.8	2.9
Total Discharge	129.5	137.5	

One goal in stream management is to provide enough water to support instream habitat while also maximizing water for other human uses off stream. Both stream discharge and instream habitat were outputs from the results of the HSHEP model, therefore we can look at the relationship between habitat and diversion amount for all of the IIFS East Maui streams. When compared to natural stream discharge at the stream mouths, full diversion removed approximately 46.5% (53.5% remained) of baseflow from the East Maui streams and under the 2018 IIFS scenario 75.5% of the baseflow was restored to East Maui streams. Baseflow restoration increased under the 30% remaining flow diversion scenario 87.4%. The restoration of an additional approximately 12% of the baseflow predicted between the 2018 IIFS scenario and the 30% remaining flow diversion scenario does result in additional habitat units. The results of the scenario tests within HSHEP model suggests that the 2018 IIFS provided a good balance between habitat restoration and water availability.

MODELING STRENGTHS and WEAKNESSES

The strength of the HSHEP model for the East Maui streams primarily centers around its ability to scenario test different water management strategies and assess its impact on native amphidromous stream animal habitat. The HSHEP model was originally designed on East Maui streams and has been improved on various other streams throughout Hawaii. The HSHEP model has passed review by the US Army Corps of Engineers for use as an impact assessment model in Hawaiian streams. Improvements in the specific HSHEP model presented here include the conversion to the R programming language and a tighter integration with streamflow discharge estimates. We also added impact assessment results associated with three native damselflies and the introduced mosquito which further broadens the applicability of the results.

The weaknesses of the HSHEP model are associated with the difficulty of validating system as complex as the EMI Aqueduct System and its impact on migratory stream animals. While the theoretical constructs of the model are well supported, quantifying specific values of entrainment, barriers to passage and loss of habitat are all difficult to specifically determine. As a result, the output of the model is best considered as a proportional depiction of the real-world habitat units available to the species within the stream. It is unlikely the specific quantification of a given habitat unit area would be close to that measured directly in a stream. This weakness needs to be placed in context of habitat suitability measurements as it is very difficult and time-consuming to document all the habitat within a complete stream system, much less over 33 extremely steep streams across East Maui. So, while the model may not result in an exact measurement of habitat units, it is likely proportionally consistent across the system as a whole and this makes it very useful for impact assessment.

An additional problem is the lack of specific discharge information, habitat surveys, or biotic surveys over much of the study area. TUTTA surveyed an additional 35 diversion locations to help ground-truth the model inputs, but many other diversions were unsurveyed. While this and other studies have been completed in the East Maui area, much of the area is unsurveyed and thus these predictions may not be accurate at these locations. While this is a weakness, the modeling approach does apply the available information in a consistent and repeatable methodology, thus the results are based on the best available information.

Overall, the combination of field surveys and habitat modeling supports the IIFS flow restoration scenario in improving instream habitat conditions for native amphidromous stream animals. While suitable habitat is fundamental for a species' persistence and is the focus of the HSHEP model, it is not the only thing that may affect species populations. Other factors, such as pollution, disease, or competition with introduced species may also influence the observed distribution and densities of native animals, yet understanding the natural distribution of animals without the presence of these additional factors is still important. From a habitat availability perspective, the 2018 IIFS does a good job at improving instream habitat over a wide range of streams.

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