# The Use of Hawaiian Stream Habitat Evaluation Procedure to Provide Biological Resource Assessment in Support of Instream Flow Standards for East Maui Streams.

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EXHIBIT F3

## Introduction:

A history of collaboration among biologists at Hawaii Division of Aquatic Resources (DAR) and researchers at various universities, agencies, museums, and private companies has focused on understanding the different aspects of the ecology and management of amphidromous stream animals (Fitzsimons and Nishimoto 2007). In recent years, efforts have focused on the development of an integrated model of Hawaiian streams that includes the life history characteristics of amphidromous animals, island stream hydrology, and critical management issues.

One result of this effort is the creation of the Hawaiian Stream Habitat Evaluation Procedure (HSHEP). This model follows the overall concepts developed by the U.S. Fish and Wildlife Service 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 Indexes (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 should 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 use of the HSHEP to assess changes in stream animal habitat in Hawaii, particularly with respect to stream diversions. Traditional HEP procedures have been joined with more recent 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 can be more appropriately modeled (Figure 1). As a result of the combination of the HEP method with multi-scale analysis, management issues can be addressed on a site, stream segment, whole stream, or region level. This report focuses on stream diversions on East Maui and further documentation on the use of HSHEP in other management areas (e.g., land use change, stream channel alteration, climate change, stream restoration, etc.) is planned for publication in the near future.

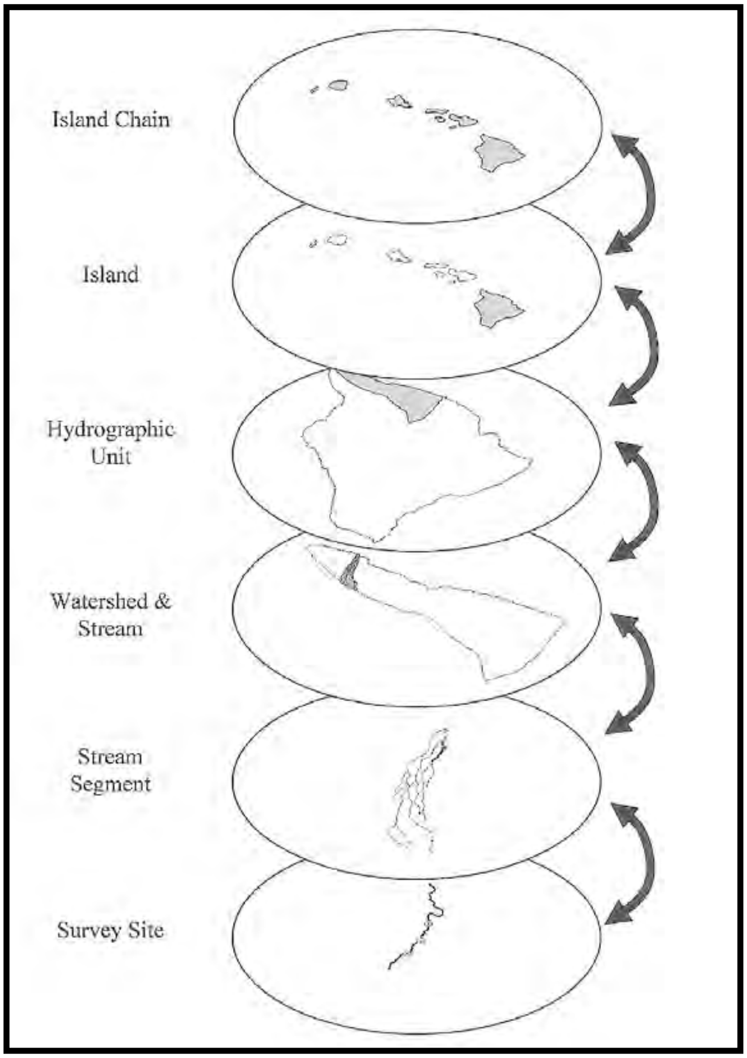


Figure 1. Spatially nested hierarchy of the DAR Aquatic Surveys Database and predictive levels within the HSHEP model.

## Request for assessment

In Hawaii, the Commission on Water Resource Management (CWRM) has the responsibility to establish instream flow standards that balance beneficial instream and offstream uses of stream water. One aspect of the beneficial instream use of water is for "the protection and maintenance of fish and wildlife habitat." A request for assessment of the biological resources for 27 petitioned East Maui streams was made by CWRM to DAR. Biologists and technicians surveyed streams in East Maui in response to the request from CWRM during the past two years. The results of these surveys documenting the current conditions within each stream are available in a series of reports pertaining to the findings for each stream (see DAR stream reports in literature cited section for specific stream report).

To adequately assess the impact of the stream diversions on native stream animal habitat, documentation of current conditions is only one aspect of the analysis. The process of collecting, storing, and analyzing the information associated with native species and their stream habitats requires multiple steps (Figure 2). In regard to the potential of returning water to the stream to benefit native species, an estimate of the amount of habitat in a stream without stream diversion needs to be compared to the amount of habitat in the stream with the diversion in place. To estimate the amount of habitat in the stream under current diverted conditions, we have data from the recent DAR surveys as well as from USGS studies on native stream animal habitat in these streams (Gingrich and Wolff 2005). To estimate undiverted conditions, we need the description of the watershed and stream and a description of the habitat and distributional requirements of the stream animals. The *Atlas of Hawaiian Watershed & Their Aquatic Resources* (Parham et al. 2008) provides watershed and stream characteristics for over 400 watersheds statewide. The upcoming *Atlas of Hawaiian Stream Animals* will provide the habitat and distributional data for native fish and invertebrate species. Because the *Atlas of Hawaiian Stream Animals* is not yet published, habitat and distributional suitability information for these species of concern are presented in the methods section of this report. Finally, the HSHEP is used to develop estimates of current HU for each species in each stream and compare that to conditions with restored water flow and improved animal passage at the stream diversion sites. The results of these analyses are to provide CWRM with the capability to effectively consider biological resource needs when the balancing of instream and offstream water uses.

The general purpose of this report is four fold:

1. to explain the influence of stream diversion on the distribution and habitat availability of native stream animals;

2. to provide documentation for the HSHEP model's design, underlying data structure, and application;

3. to show changes in habitat availability for native amphidromous animals on a stream by stream basis; and,

4. to prioritize habitat and passage restoration actions among the streams of concern in East Maui.

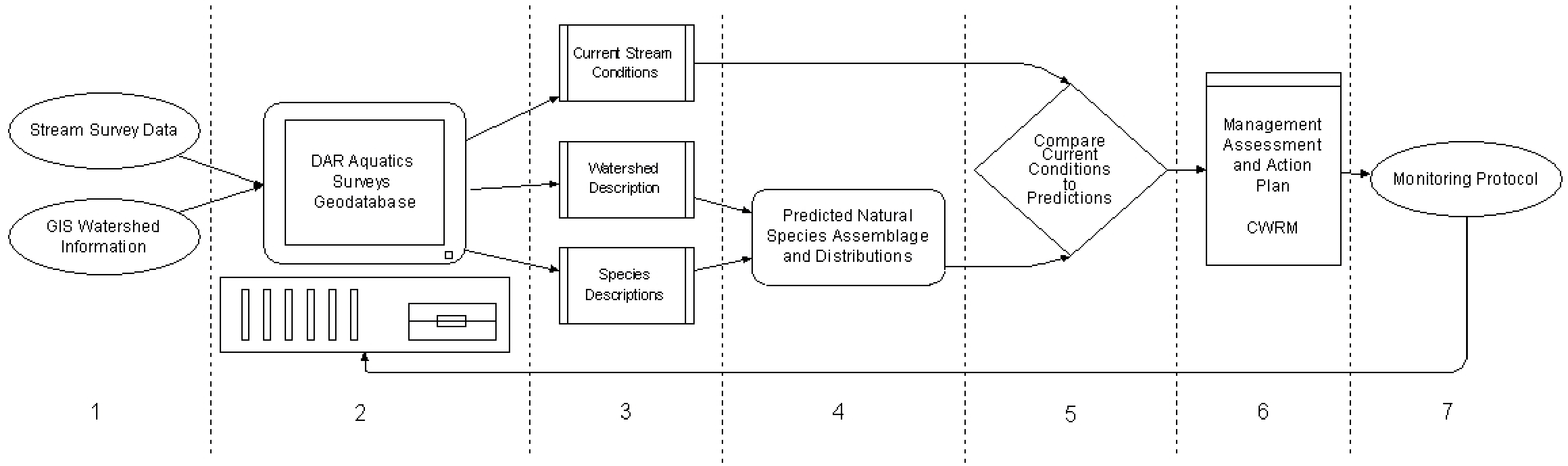


Figure 2. Stream Management Process Flow Chart. The flow chart outlines the steps and products needed to provide objective stream management assessments and monitoring efforts to support Instream Flow decision by the Commission on Water Resources Management (CWRM). Step 1 is the collection of information on the stream and its watershed. Step 2 is inputting the information into the DAR Aquatics Surveys Geodatabase. Step 3 is the production of several reports including reports detailing current stream conditions, an overall watershed description, and description of habitat and distribution of stream species. The current conditions are reported in the survey reports for each stream, the watershed description is provided in the *Atlas of Hawaiian Watersheds & Their Aquatic Resources*, and species description that have been developed from the data will be published in the upcoming *Atlas of Hawaiian Stream Animals*. Step 4 combines the description of the stream and its available habitat with species habitat use descriptions to predict the natural stream assemblage. Step 5 compares the current stream conditions with the predicted natural condition to see if the stream is functioning normally. Step 4 and 5 are accomplished using the Hawaiian Stream Habitat Evaluation Procedure (HSHEP). Step 6 is to develop an impact assessment related to biological conditions for CWRM. Step 7 is to monitor final management action determined by CWRM to see if objectives are being met and also to add new data to the DAR Aquatics Surveys Geodatabase to improve the predictive capabilities of DAR in future projects.

From a management perspective, stream diversions have differing affects on the life history traits of native stream animals. While the HSHEP model attempts to capture many of the potential effects, not all can be adequately modeled at this time. Even though some of the potential issues caused by stream diversion are not addressed in the HSHEP model at this time, the design of the HSHEP model will allow for the inclusion of information on these issues as data become available. The following is a discussion of the potential affects that stream diversions may have on the different aspects of amphidromous animals' life history. The specifics regarding how the HSHEP addresses these issues are provided in the methods section.

### Stream diversion and native amphidromous animals.

Native amphidromous animals in Hawaiian streams share similar life history traits (McDowall 2007). In general the animals have an oceanic larval phase where they develop in the open ocean for up to six months.  This is followed by recruitment to stream as the larvae metamorphose to postlarvae. The postlarve then migrate upstream to suitable habitat and complete their development into juvenile animals. Within the suitable stream habitat the juveniles grow to adults and then reproduce. The newly hatched larvae drift downstream back to the ocean to undergo their oceanic larval phase. As a general model, the important phases can be separated into (1) oceanic larval phase, (2) recruitment, (3) upstream migration, (4) instream habitat, and (5) downstream migration and drift.

### Oceanic Larval phase:

Amphidromous animal larvae living in the ocean as zooplankton during their oceanic larval phase are situated in full strength sea water (Radke et al. 1988). Whether the larvae drift widely offshore or stay near the islands in nearshore currents is unknown (Hobson et al. 2007, Murphy and Cowan 2007), but in either case there would be little or no influence of stream flow or stream habitat on this phase, and therefore no management actions related to stream diversion structures will influence the species' oceanic larval phase.

While no direct management actions regarding stream diversion will influence the success of the oceanic larval phase, the oceanic larval phase has a role in the overall management philosophy of amphidromous animals. Murphy and Cowan (2007) discussed the possible patterns and implications of the oceanic larval phase. Although it is unknown at this time if the larvae drift passively on the ocean currents or show directed movement to stay near the islands, the larvae face many obstacles to complete their oceanic larval phase and successfully recruit to a stream. Larvae may be eaten, starve, or drift off into the open ocean. The chance for all necessary conditions lining up correctly for larvae to successfully complete this phase and recruit to suitable habitat has been likened to a winning a lottery (Sale 1978). As a result, a direct linear relationship between larvae spawned in a stream and larvae returning to a stream is highly unlikely. Given the unknowns and uncertainties associated with the oceanic larval phase, management strategies that maximize the production of larvae to the oceanic plankton pool and maximize the distribution of suitable habitat where larvae may recruit will improve the "odds of winning the recruitment lottery." While predicting the specific species, number, or time of recruitment to a specific stream may prove difficult, management actions that improve instream habitat and ultimately reproductive output are likely to result in more successful recruitment events and thus promote more stable populations among a group of streams.

In summary-

- Management actions that improve reproductive output will likely increase chances that some animals survive the oceanic larval phase.
- Management actions that improve instream habitat across a group of streams will increase the chance that suitable habitat will be encountered as the larvae end their oceanic phase and begin recruitment.

## Recruitment:

There is some evidence that the freshwater plume created by stream discharge into the ocean draws recruiting animals to a stream (Nishimoto and Kuamoʻo 1997). It is theorized that larger freshwater plumes will attract more recruiting animals. Amphidromous animals tend to recruit *en masse* (Nishimoto and Kuamoʻo 1997). As a result, the number of recruiting animals during a single recruitment event may not be tightly linked to the size of the freshwater plume, but the chance of the recruitment event occurring should be related to the ability of the animals to detect the stream (Figure 3 and 4). In other words, if the mass of recruits is viewed as a single group or unit, the number of recruitment units that detect a stream’s freshwater plume will be greater for a stream with a larger plume that occurs for a larger percentage of the time.

Figure 3.  Two images of the mouth of Pi’ina’au Stream, Maui. The left image shows the amount of freshwater discharged into the ocean at low flows and the right image shows the amount of water discharged at high flows. Notice the color change in the ocean in the right image, where increased discharge (and increased sediment load) has a much larger area of influence in the ocean.

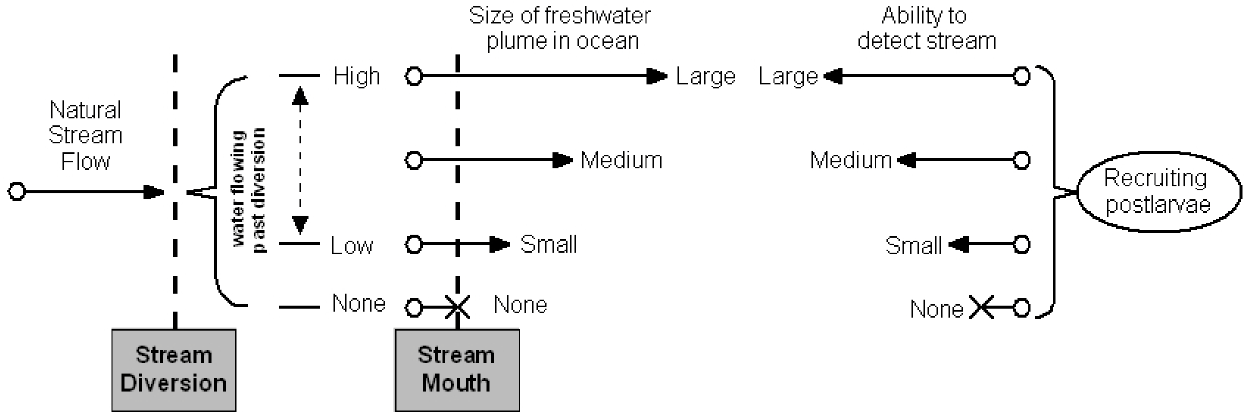


Figure 4. A conceptual model describing the role of streamflow into the ocean in attracting recruiting postlarval animals to the stream. Stream diversions decrease the size of the freshwater plume and therefore make it harder for recruiting animals to detect the freshwater from their offshore larval development areas.

In addition to the size of the freshwater plume, in many streams a stream mouth berm is created when deposition from wave action is greater than erosion by stream flow (Figure 5). The stream mouth berm acts as a barrier to recruitment. While the creation and destruction of a stream mouth berm is a natural phenomenon for many streams, decreases in stream flow as a result of stream diversion will decrease the erosive power of the stream water and increase the period of time that a berm may exist (Figure 6). Conversely, increased stream flow will decrease the amount of time that a stream remains closed by a berm and therefore blocked to recruitment.

Figure 5. Two photographs of the mouth of Kopiliʻula Stream, Maui. The image on the left shows a closed stream mouth berm and the image on the right show the berm open. Notice the lower stream discharge on the left (i.e., more exposed rocks in stream and no white water in the upper riffle) as compared to the higher discharge on the right.

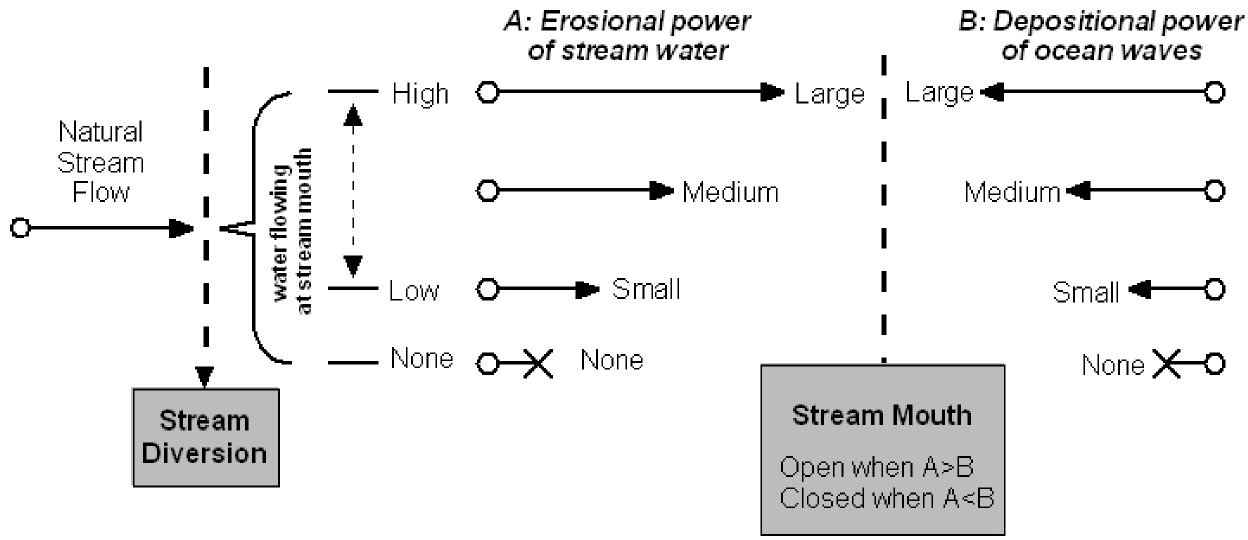


Figure 6. Conceptual model of the balance between stream power and ocean power in controlling the presence or absence of a berm at the stream mouth. When the stream mouth is open, recruiting stream animals can easily move upstream, while when a stream is closed by a berm, recruitment into the stream is highly restricted.

Management actions that increase freshwater discharge into the ocean are likely to improve recruitment by attracting more groups of recruiting animals and expanding the window of opportunity for recruits to enter an open stream mouth. Additionally, there is evidence that the presence of adult animals within a stream may draw recruiting individuals of the same species (Hobson et al. 2007). Therefore, management actions that improve adult populations in a stream may improve overall recruitment to the stream.

In summary-

- Management actions that increase the size of the freshwater plume will likely result in more recruitment events.
- Management actions that increase the time that the stream mouth is open will provide a longer window for recruitment events to occur.
- Management actions that increase instream adult population may attract more recruits.

**Upstream migration**:

Different species display different upstream migration capabilities (Schoenfuss and Blob 2007). Instream obstacles that prevent upstream movement for one species may be easily surmounted by another species (Figure 7). In general, differences in stream gradient or waterfalls height are measurable natural barriers to upstream migration for specific species.

Figure 7. Examples of potential natural barriers to upstream migration. Waterfalls are barriers to some species, while other species with the ability to climb may surmount the waterfall and continue moving upstream. The images show two different waterfalls in Maui streams. The left image (Honomanū Stream) shows a tall waterfall where the water is in contact with the face of the waterfall. Some species will be able to pass this type of waterfall. The right image (Honopou Stream) shows an undercut waterfall. An undercut waterfall will be a barrier to upstream migration for amphidromous species unless a wetted pathway exists for the animals to bypass the undercut.

Just as natural barriers exist in streams, some instream diversion structures can act as barriers to upstream migration. The diversion structures can be a physical barrier, create dry sections that prohibit movement by aquatic species, or entrain animals as they attempt to pass over the diversion structure. While the dry section is a direct result of water withdrawals, the other two factors (physical barrier or entrainment) are related to the design of the structure. As with natural barriers, species-specific differences in migratory ability influence whether or not an instream diversion structure is an actual barrier to a species.

Physical barriers that prevent the upstream migration of amphidromous animals are perhaps the most obvious barrier effect of stream diversions. Physical barriers can result from many different designs, but the major issues are height of the dam wall, inappropriate hydraulic conditions, or the creation of an overhanging drop-off (e.g., pvc pipes) in the stream channel (Figure 8). Given the climbing ability of most amphidromous animals found in the middle reach to the headwaters of Hawaiian streams, as long as the height of structure is not substantially greater than natural waterfalls occurring downstream of the diversion location then the vertical wall should have minimal impact on upstream migration.  In cases where a dam is located in a relatively low gradient stream, blockage of upstream migration may be a problem.

Physical structures may also form hydraulic or behavioral barriers. If the structure creates a flow that is too fast or turbulent for animals to pass through then it can stop upstream migration. Additionally, some animals may have behavioral responses to the physical structure that prevent them from passing through the structure. For example, an animal may avoid passing through a pipe due to its darkness or its smooth sides. Currently, no studies address the hydraulic or behavioral aspects of barriers in Hawaiian streams, although preliminary studies suggest the larvae move mostly during the day and may avoid black plastic pipes (Burky et al. 1999).

In contrast to the height of the diversion, the creation of an overhanging drop off is a problem for migrating animals where ever it is encountered in the stream. Amphidromous animals require contact to a continuous wetted surface in order to climb an obstacle. If the water falls freely from the lip of the drop-off to the pool below then the animals cannot pass the structure (Figure 9). This situation typically occurs where a structure has been undercut by erosion on the downstream side or where a pipe is used to convey water downstream and the downstream pipe outlet is higher than the surface of the water below and extends out beyond the surface that supports it. Both of these situations can completely eliminate upstream migration, but are relatively easy to remedy by re-engineering the structure to remove the overhang.

Figure 8. Vertical drop as a barrier on ʻĪao Stream, Maui (left) and a pipe providing for water flow downstream over a diversion on Hanehoi Stream, Maui.  While not actual stream diversions, the images show potential obstacles that animals migrating upstream may encounter. Notice the extent of the drop in comparison to the normal channel gradient in left image. In the right set of images, it is unknown if hydraulic conditions (too swift or turbulent flow) or the unsuitable substrate (smooth pipe may prevent animals from holding on to pipe sides) would prevent upstream migration. Additional behavioral issues may also be a factor in the extent of fish passage through the pipe (fish may avoid dark areas).

Figure 9. Over hanging diversions on Honopou Stream, Maui (left) and on the middle reach of Waiheʻe Stream, Maui (right). Notice how the water free falls and leaves no pathway for upstream migration.

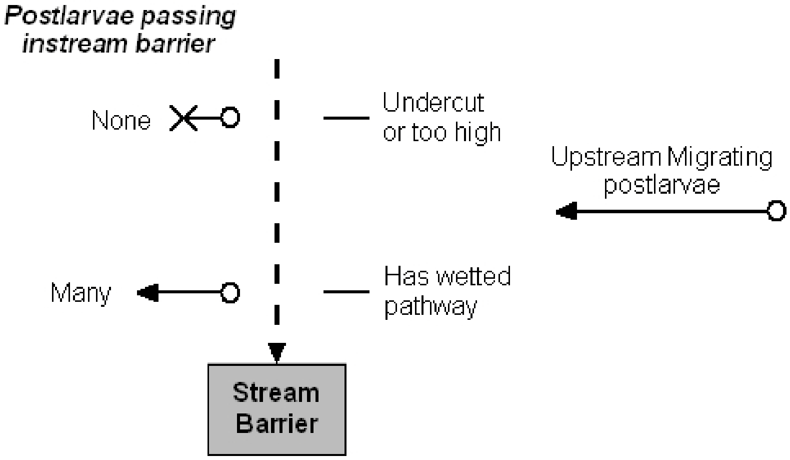


Figure 10. Conceptual model of the physical blockage of upstream migration instream structures.

Stream diversions may also result in the dewatering of a section of stream. This disruption of the physical connection between the upstream and downstream sections prevents the passage of migrating postlarvae to suitable adult habitats (Figure 11). In most native amphidromous fishes, the majority of upstream movement is accomplished prior to adulthood (Schoenfuss and Blob 2007). As the fish grow they become less capable climbers, therefore, the extent of time that a stream section is dewatered is critical to upstream migration of native stream animals. The issue of the time available for upstream movement is also important for the freshwater snail, *Neritina granosa*, as it moves slowly during migration and is susceptible to being stranded in dry sections (Hau 2007). A dewatered stream section can be viewed as a gate with respect to upstream migration (Figure 12). When water is present and flowing through the section, the section is open to upstream migration and when the stream section is dry, the section is closed to upstream migration. The following pictures show a stream bed closed and open to upstream migration as a result of stream diversion and rainfall (Figure 11).

Figure 11. Two photographs of Kopiliʻula Stream, Maui. Both images are from stream sections downstream of the stream diversion. Notice how during periods of low stream discharge (left image) the stream pools are disconnected with dry streambed between the pools, while during periods of higher stream discharge (right image) the stream is fully connected and provides a migratory pathway for animals moving upstream.

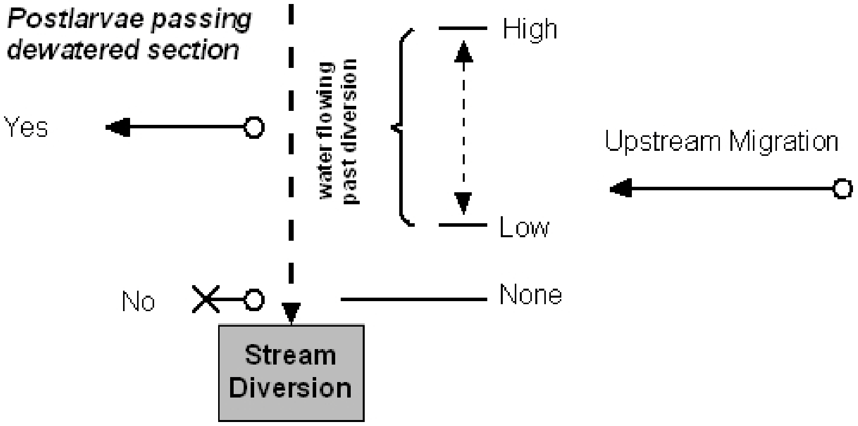


Figure 12. Conceptual model showing the probability of upstream passage by postlarvae of native amphidromous stream animals. Upstream movement would be possible when water is flowing past the diversion and provides a continuous pathway through previously dewatered stream section.

The final impact stream diversions may have on upstream migration is entrainment of individual postlarvae as they pass over the diversion structure. Depending on the design of the diversion structure, migrating animals may be entrained in the diversion and removed from the stream population (Figures 13 and 14). Many diversion structures on Hawaiian streams divert water through a grate into a diversion ditch. Entrainment into the ditch would not only be possible, but likely with the typical diversion design.

Figure 13. Two images of Honopou Stream, Maui at low (left) and high (right) flows. At low flow the barrier is a complete blockage to upstream migration and at high flow most of the water flows through the diversion structure. As postlarvae move upstream through the structure, many would be entrained in the diverted waters and removed from the stream.

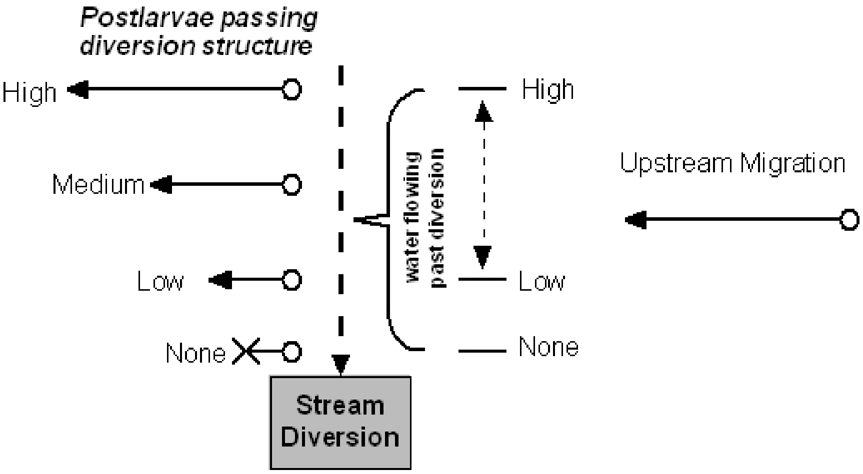


Figure 14. Conceptual model of the extent of upstream passage by postlarvae of native amphidromous stream animals. Entrainment of postlarvae would be a function of the proportion of amount of water passing the diversion and the amount flowing into the diversion.

From a management perspective, the maintenance of adequate stream flow from upstream adult habitat to the stream mouth is critical for amphidromous animals. Given the vagaries of the timing recruitment and the short developmental window for upstream movement, minimizing the time that barriers to upstream movement exist will increase the chance that suitable upstream habitat will be colonized by newly recruiting animals. The entrainment by diversion structures of migrating animals is a direct loss of animals. At the point where the animal has successfully survived the oceanic larval phase, found a suitable stream to recruit to, undergone substantial development changes, and moved upstream, the loss of an individual at this stage is costly to the adult population. Allowing for passage through stream diversion structures to suitable upstream habitat will likely result in greater upstream population densities of amphidromous animals.

In summary-

- Management actions that minimize barriers to upstream migration will increase settlement of juveniles in suitable upstream habitats.
- Management actions that increase the window of time that a pathway from the stream mouth upstream to suitable habitats is available will increase the chances that when a recruitment event occurs the postlarve will be able to move upstream to suitable habitats.
- Management actions that decrease entrainment of upstream migrating animals will increase the number of juveniles that settle in suitable upstream habitats.

**Instream habitats:**

Native Hawaiian stream animals move upstream to select suitable instream habitats for growth and reproduction. These habitats are typically described in terms of their physical characteristics (i.e. depth, velocities, substrates, water quality) or descriptive characteristics (i.e. riffle, run, pool). The instream habitats are influenced by the surrounding land cover and upstream conditions. From a hydraulic perspective, stream habitats observed at low discharge are created and maintained at high discharge. For example, while a stream pool is a slow, deep habitat at low discharge, at high discharge the pool is an erosional zone with swift scouring flow. A riffle is a depositional zone at high discharge and swift, shallow water at low discharge. Runs typically transport sediment over a range of discharge rates. It is important to remember that observed instream habitats are result of both high and low discharge events.

Stream diversions influence instream habitat in several ways. First there is the physical structure that replaces the local instream habitat. In general, this is a minor change to the overall stream habitat as most diversions act as a pool/riffle or pool/waterfall combination. In numerous places, native stream animals have been observed in the pool created by the diversion and in terms of total area of habitat, the stream diversion itself modifies a relatively small area.

The more obvious way that instream habitat is affected by stream diversions is the decrease in habitat area as a result of the removal of water from the downstream channel (Figures 15 and 16). In the most extreme cases, the diverting of 100% of the water can result in the elimination of all habitats downstream of the diversion by dewatering the downstream sections. At lower percentages of diversion there is a decrease in wetted area, depths, and velocities (Kinzie et al. 1986). The exact relationship between the change in habitat area and discharge is controlled by the geomorphology of the site in question. Habitat models suggest that changes in wetted area are closely related to available habitat for native Hawaiian stream animals (Gingerich and Wolff

2005). Observational data collected at many locations in many different streams indicate that suitable habitat requires at least 12 inches of water depth in a habitat unit for most native stream species and sites with water less than six inches are generally unsuitable for adult native species (Parham 2008).

In addition to the loss of habitat area, water removal may result in a decrease of the suitability of the remaining habitat. While the amount of habitat available at low discharge levels is important, the timing and duration of these low discharge events are also important. Instream habitat is a balance between sediment transport dynamics at high and low discharge and holding a stream permanently at low discharge levels will result in a gradual change in the observed instream habitats. Lack of scouring flow generally leads to the filling of deeper habitats and embedding of larger substrates with smaller sediment and these are not suitable characteristics of native animal habitat (Kido 2002). Lower discharge rates can also result in warmer water temperatures with the sun heating the slower, shallower water more quickly than the deeper and swifter waters. Warmer water holds less oxygen than cooler water and increases bioenergetic demands on the ecothermic stream animals.

Figure 15. Changes in instream habitat after stream diversion on Hononmanū Stream, Maui. The diversion, downstream of the surveyors, was diverting 100% of stream flow (left picture). Downstream of diversion (right picture) there is no water flow and no habitat for aquatic animals.

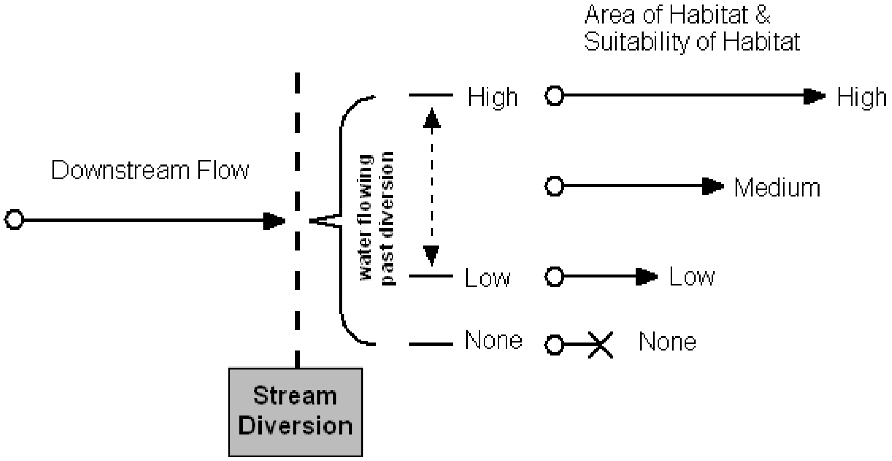


Figure 16. – Conceptual model of the influence of stream diversion on instream habitat.

From a management perspective, instream habitat needs to provide adequate conditions for the animals to survive during drought conditions, provide cover to avoid predation and high flow events, supply enough food resources to grow, and provide suitable reproductive habitats. The presence of an animal in a site is not the only criteria needed to determine if the site has all characteristics necessary for the animal to complete its life cycle.

In summary-

- Management actions that provide stream discharge patterns in diverted streams that mimic natural discharge patterns with both high and low flows are likely to sustain suitable instream habitats and amphidromous animal populations.
- Management actions that avoid dewatering a streambed will provide substrate for algae (especially diatoms) and habitat for aquatic invertebrates which provide food sources for amphidromous animals
- Management actions that maintain water flow throughout the stream will minimize water quality problems, improve instream habitats, and allow movement of amphidromous animals among habitats.
- Management actions that maintain suitable water depth in pools and runs, especially at low flows, will provide cover for amphidromous animals to avoid avian predation.
- Management actions that maintain suitable water depth, especially at low flows, will assure nests and eggs of amphidromous animals do not dry up.

**Downstream movement (migration and drift):**

Downstream movement in amphidromous animals may involve both adult and larval phases. In some species, adults may migrate from upstream locations to downstream locations to spawn (Kido and Heacock 1992, Fitzsimons et al. 2007). In all native amphidromous animals, downstream larval movement is accomplished by drifting with the stream current. The timing of the larval metamorphosis from a freshwater to saltwater larvae is measured in days and the larvae must reach saltwater to complete this transformation (Lindstrom 1998, Iguchi and Mizuno

1999, Iguchi 2007, McRae 2007). Therefore, travel time from hatching site to the ocean is critical to downstream migration of native stream animals (McRae 2007).

Similar to upstream migration issues, stream diversions result in two separate mechanisms to prevent or reduce downstream migration and drift. Stream diversion may result in the dewatering of a section of stream. The dewatered stream section is a disruption of the physical connection of upstream sections with downstream sections preventing the passage of adults moving downstream or newly hatched larvae drifting to the ocean. Even if a stream diversion does not create a dewatered stream section, the diversion may decrease downstream water velocities as a result of the overall decrease in stream discharge. Average water velocity is a function of stream discharge and gradient. A decrease in the amount of water will result in slow stream flow velocities. As stream velocities decrease, fewer larvae can reach the ocean within an appropriate time to allow for metamorphosis into their larval phase (Figure 17) (Bell 2007). A diverted stream section can be viewed as a dial with respect to downstream drift (Figure 18). As one turns the dial upward, stream flow increases and a larger number of drifting larvae will successfully reach the ocean from their hatching sites upstream.

Figure 17. Three images of Hakalau Stream, Hawaii captured at different stream discharge rates. Notice the increased amount of swift water (i.e. white water) as stream discharge increases. The time for a drifting embryo to transit the distance of the image would decrease with increased stream discharge.

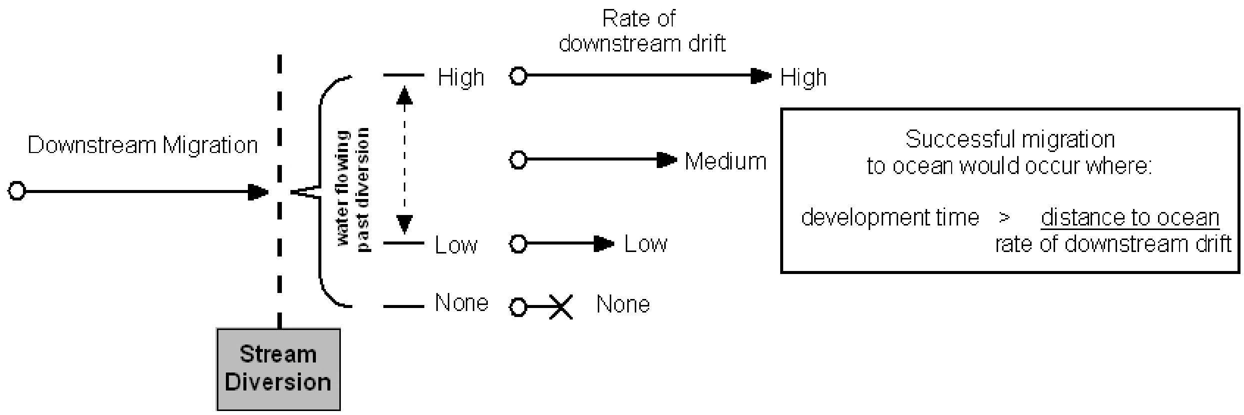


Figure 18. Conceptual model of the influence of stream diversion on travel time and ultimately the success of downstream drifting embryos of native amphidromous stream animals in reaching the ocean within a suitable development period. Successful downstream migration would be a function of rate of downstream drift and the distance to the ocean.

Stream diversions also have a second effect on downstream movement. Depending on the design of the diversion structure, both adult and larval animals may be entrained in the diversion and removed from the stream population (Figure 19). Many diversion structures on Hawaiian streams divert water through a grate into a diversion ditch. Entrainment into the ditch would be possible and likely with the typical diversion design. Typical stream diversion structures divert 100% of the water at low to moderate flows. Under these conditions, 100% of downstream moving individuals would be entrained by the diversion. As stream flows overtop the diversion, a portion of the animals would likely pass the diversion and continue downstream (Figure 20).

Figure 19. Stream diversion intakes on Waiheʻe Stream (left) and Honopou Stream, Maui (right). Notice how 100% of the water flows into the diversion at this discharge. An animal moving downstream would be transported with the water and entrained in the diversion structure resulting in 100% mortality.

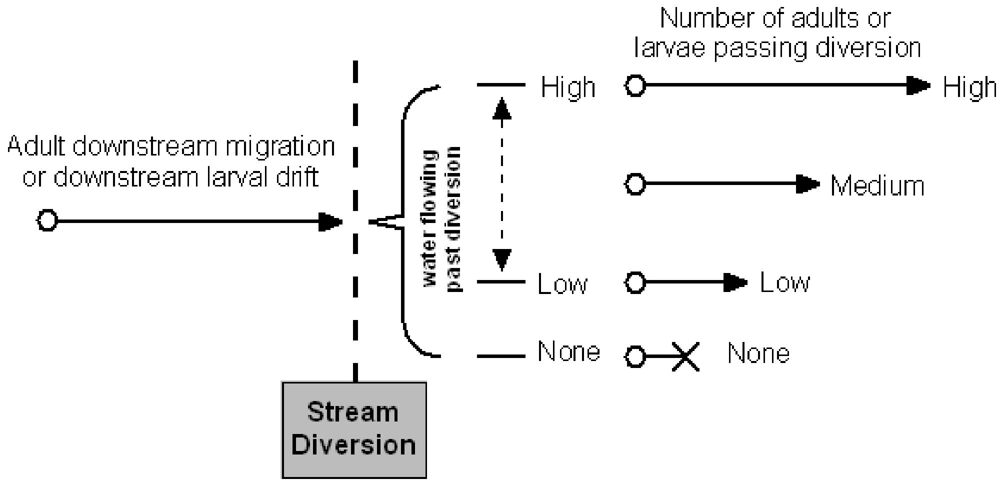


Figure 20. Conceptual model of the extent of diversion passage by downstream migrating adults or downstream drifting larvae of native amphidromous stream animals. Entrainment would be a function of the proportion of amount of water passing over the diversion to the amount flowing into the diversion.

From a management perspective, providing for adequate passage and timely transport of newly hatched larvae to the ocean are important factors in successful downstream migration. In this respect, suitable stream habitat is more valuable if it is located near the ocean than if it is far inland or above a stream diversion site (McRae 2007). Assuring that newly hatched larval animals reach the ocean from the upstream nesting sites, coupled with successful completion of the other phases of the amphidromous animal's life history, results in ecological connectivity between ocean and stream habitats.

In summary-

- Management actions that decrease travel time from the nest site to the ocean for newly hatched larvae will increase the number of larvae that survive and successfully reach the ocean.
- Management actions that decrease entrainment of migrating adults and downstream drifting larvae will increase the number of adults that survive downstream migration to spawning sites and increase larvae that survive and successfully reach the ocean.

Overall, stream diversions interact with the native amphidromous animals found in Hawaiian stream in many different ways. Fundamentally, aquatic animals live in the water and diversions remove that water from the stream. The issue is not so much, if stream diversions have an impact on stream animals and their habitats, but rather how can we minimize the impacts of stream diversion on native stream animals while still meeting society's needs for freshwater (Devick 2007). The following sections of this document outlines the development and application of a habitat evaluation Procedure that provides a standardized way to assess a diversion's impact on stream animals and then subsequently prioritizes restoration opportunities that would result in the most positive benefits to stream animal populations.

## Description of the HSHEP model for the East Maui Streams:

To quantify the current conditions of the stream and to estimate the affect of stream diversions on native stream animal habitat, the Impact Assessments techniques of the Habitat Evaluation Procedure (HEP) were followed. The impact assessment involves several steps including:

1) description of study area;
2) selection of evaluation species;
3) definition of model;
4) description of suitability indices at each spatial scale;
5) quantification of expected "non-diverted" habitat units (HU) within the study area; and,
6) estimation of HU within the study area gained by water return.

1) Description of study area

For the purposes of this impact analysis, the study area includes 16 streams and their tributaries chosen by the Commission on Water Resources Management and covers all stream habitats from the stream's headwaters to the ocean. These streams are located on the windward side in the eastern half of Maui.

Table 1. Streams and their corresponding DAR Watershed ID.

| Number | Stream Name[1] | Watershed ID |
|---|---|---|
| 1 | Kōlea | 64003 |
| 2 | Waikamoi | 64004 |
| 3 | Puohokamoa | 64006 |
| 4 | Haipuaʻena | 64007 |
| 5 | Punalau | 64008 |
| 6 | Honomanū | 64009 |
| 7 | Nuaʻailua | 64010 |
| 8 | ʻŌhiʻa | 64012 |
| 9 | W. Wailua Iki | 64015 |
| 10 | E. Wailua Iki | 64016 |
| 11 | Kopiliʻula | 64017 |
| 12 | Waiohue | 64018 |
| 13 | Paakea | 64019 |
| 14 | Kapāʻula | 64021 |
| 15 | Hanawī | 64022 |
| 16 | Makapipi | 64023 |

[1] An additional stream, Waiaʻaka Stream, was included on the list, but was not included in DAR's stream codes, database, or GIS coverages and therefore it was not included in this analysis. DAR has added a Watershed ID for Waiaʻaka Stream (64020). Two additional tributaries were included in the CWRM list; we included the tributaries with the overall stream. For further

descriptions of each watershed see the *Atlas of Hawaiian Watersheds & Their Aquatic Resources* (Parham et al. 2008).

2) Selection of evaluation species

For the purposes of quantifying habitat in East Maui streams, information on native animals of special concern was requested by CWRM and therefore these species were selected for use as evaluation species (Table 1). These animals make up the majority of the native species observed during the DAR point quadrat surveys and have a substantial amount of habitat information available within the DAR Aquatics Surveys Database.

Table 2. Species to be evaluated for each of the 19 streams of concern on Maui requested by CWRM.

| Organism Type and Family | Scientific name | Hawaiian name |
|---|---|---|
| Freshwater fish<br>(family Gobiidae) | *Awaous guamensis** | ʻOʻopu nākea |
| | *Lentipes concolor** | ʻOʻopu alamoʻo |
| | *Stenogobius hawaiiensis** | ʻOʻopu naniha |
| | *Sicyopterus stimpsoni** | ʻOʻopu nōpili |
| Freshwater fish<br>(family Eleotridae) | *Eleotris sandwicensis** | ʻOʻopu akupa |
| Freshwater shrimp (Crustacean)<br>(family Atyidae) | *Atyoida bisulcata** | ʻŌpae kalaʻʻole |
| Freshwater prawn (Crustacean)<br>(family Palaemonidae) | *Macrobrachium grandimanus** | ʻŌpae ʻoehaʻa |
| Freshwater snail (Mollusk)<br>(family Neritidae) | *Neritina granosa** | Hīhīwai |

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

3) Definition of the model

To develop the impact analysis for these streams, the Hawaiian Stream Habitat Evaluation Procedure (HSHEP) Model was used to quantify the suitable HU for native amphidromous stream animals. The HSHEP model has been under development by researchers from DAR and Bishop Museum for several years. DAR has been cataloging distribution and habitat information on Hawaiian streams animals into a relational database (DAR Aquatics Surveys Database) with a focus on the native amphidromous fishes and macroinvertebrates. The information collected on these animals provides the suitability index related to the various distribution and habitat criteria described in the following section. The species specific suitability indices are described in Section 4 of the methods.

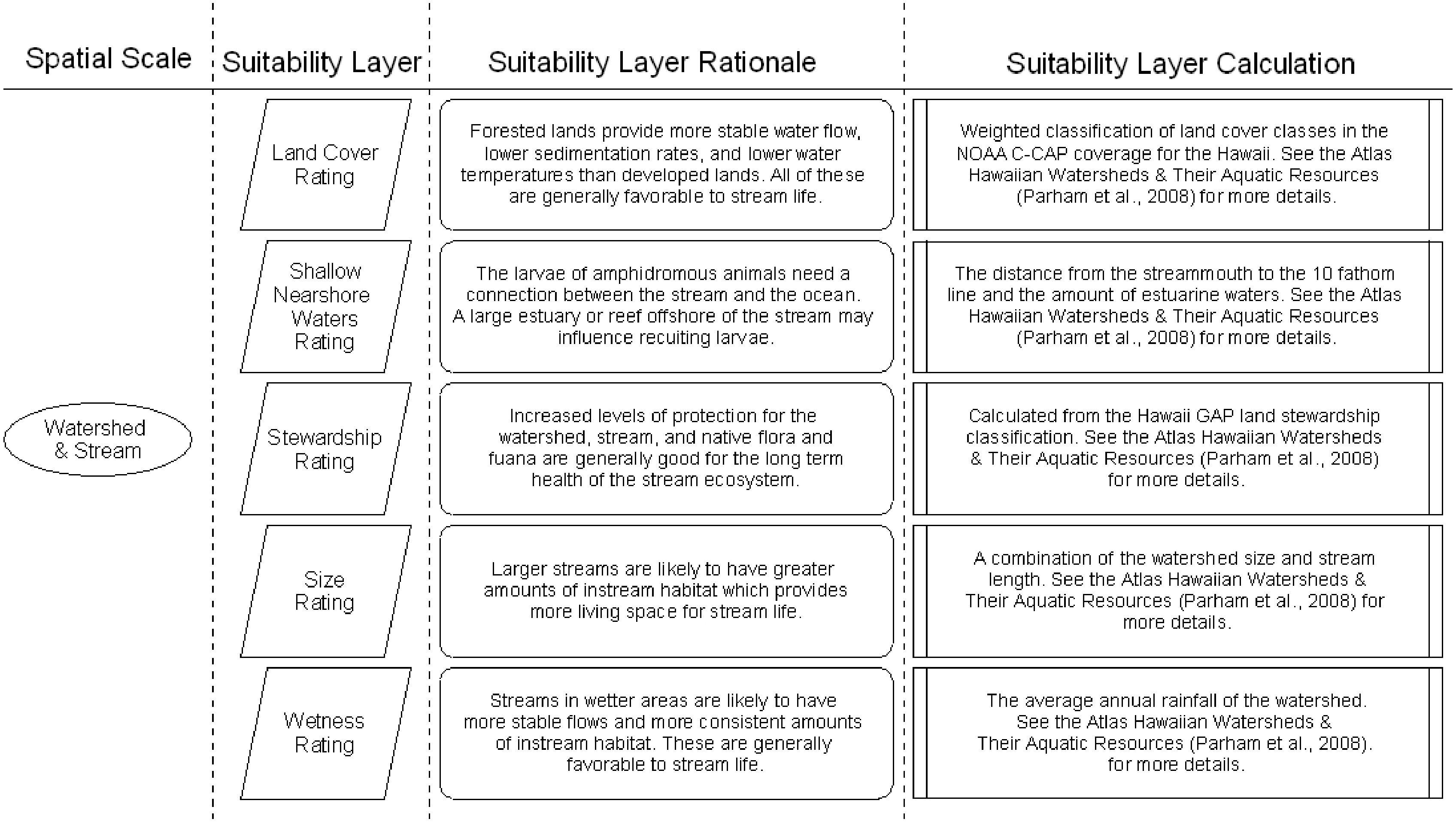
The HSHEP is based on a nested spatial hierarchy (Figure 1). Depending on the question being modeled, various levels of the hierarchy are used. In this report, the spatial levels for watershed, stream segment, and site will be used. The spatial levels of island chain, island, and region are not needed as all streams are located on the same island within the same region.

At the watershed level, variables include stream and watershed size, watershed wetness, watershed stewardship, the amount of estuary and nearshore marine associated with the watershed, the watershed land cover quality. The rating for these variables was presented in the the *Atlas of Hawaiian Watersheds & Their Aquatic Resources* (Parham et al. 2008) and the variable for all 430 streams included in the atlas are used to develop the model at this level. A flow chart of the watershed and stream spatial level is shown in Figure 21.

At the stream segment level, variables include elevation, distance inland from the ocean, and the slope of instream barriers (Figure 22). Native amphidromous animals are diadromous requiring a connection between the freshwater streams and the ocean to complete their life cycle. Thus the ability of the animal to move upstream from the ocean will influence its observed distribution.

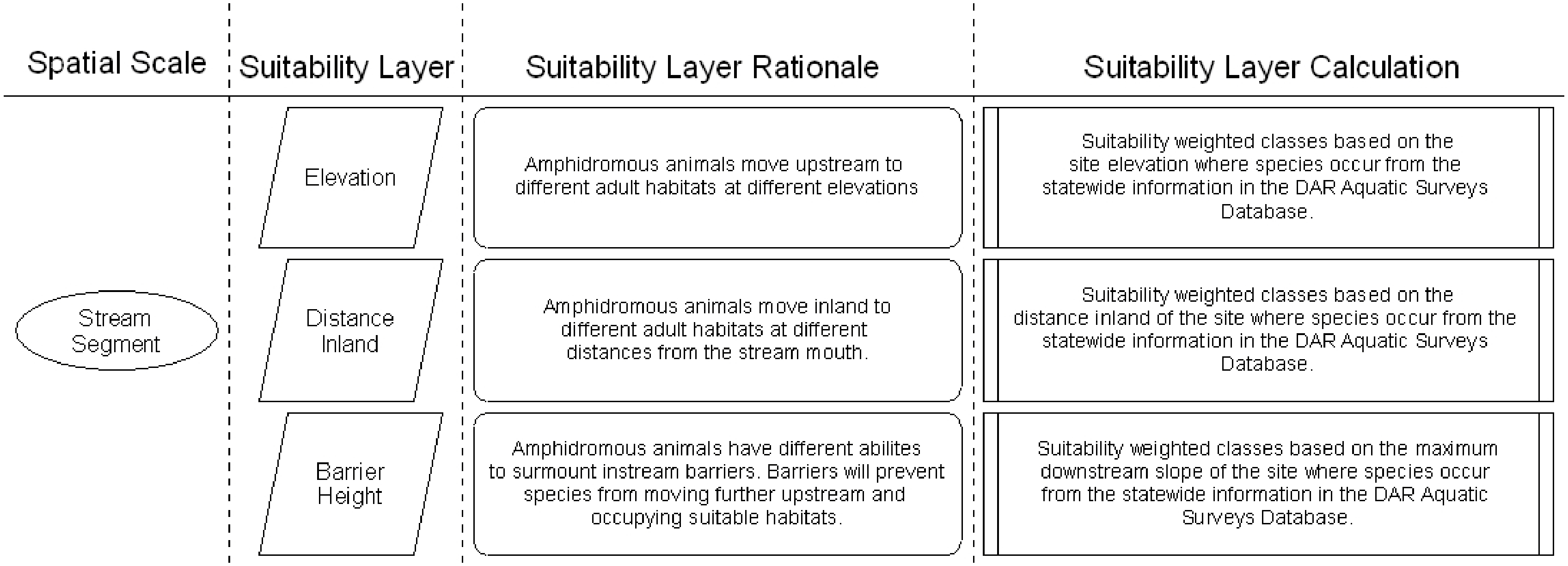
At the site level, more specific habitat characteristics are important. Water depth, temperature, velocities, bottom composition, and habitat type are used to describe suitable habitat for a species at this spatial scale (Figure 23). For the HSHEP analysis used for the East Maui streams reported here, the generalized suitability indices developed from statewide stream surveys were replaced by the stream discharge to habitat relationships developed by the USGS for these streams. The USGS IFIM information covers similar habitat characteristics and was developed from field survey information collected specifically to address stream diversion issues on these streams.

By combining the different spatial scales it is possible to assess habitat suitability with respect to its location in a stream and compare that stream to all other streams in the Hawaiian Islands. The presence of suitable site characteristics is only important if the species can reach the habitat, thus site presence is also influenced by the higher spatial scales. For example, a deep, clear stream pool with a mixture of cobble and boulder habitat may be highly suitable for a number of native species, yet if that pool is found far inland and above a high waterfall, only a few species could be expected to inhabit the pool. Additionally, those two similar suitable pools may exist at comparable distances inland and elevations, but if one is in a stream that is large and has ample rainfall during the year, while the other is small and receives limited rainfall, it is unlikely that the observed occupancy of each pool will be similar.



| Spatial Scale | Suitability Layer | Suitability Layer Rationale | Suitability Layer Calculation |
|---|---|---|---|
| Watershed & Stream | Land Cover Rating | Forested lands provide more stable water flow, lower sedimentation rates, and lower water temperatures than developed lands. All of these are generally favorable to stream life. | Weighted classification of land cover classes in the NOAA C-CAP coverage for the Hawaii. See the Atlas Hawaiian Watersheds & Their Aquatic Resources (Parham et al., 2008) for more details. |
| | Shallow Nearshore Waters Rating | The larvae of amphidromous animals need a connection between the stream and the ocean. A large estuary or reef offshore of the stream may influence recuiting larvae. | The distance from the streammouth to the 10 fathom line and the amount of estuarine waters. See the Atlas Hawaiian Watersheds & Their Aquatic Resources (Parham et al., 2008) for more details. |
| | Stewardship Rating | Increased levels of protection for the watershed, stream, and native flora and fuana are generally good for the long term health of the stream ecosystem. | Calculated from the Hawaii GAP land stewardship classification. See the Atlas Hawaiian Watersheds & Their Aquatic Resources (Parham et al., 2008) for more details. |
| | Size Rating | Larger streams are likely to have greater amounts of instream habitat which provides more living space for stream life. | A combination of the watershed size and stream length. See the Atlas Hawaiian Watersheds & Their Aquatic Resources (Parham et al., 2008) for more details. |
| | Wetness Rating | Streams in wetter areas are likely to have more stable flows and more consistent amounts of instream habitat. These are generally favorable to stream life. | The average annual rainfall of the watershed. See the Atlas Hawaiian Watersheds & Their Aquatic Resources (Parham et al., 2008). for more details. |

Figure 21. Schematic of the Watershed and stream spatial scale including variables used in the model to predict species occurrence in a stream.



| Spatial Scale | Suitability Layer | Suitability Layer Rationale | Suitability Layer Calculation |
|---|---|---|---|
| Stream Segment | Elevation | Amphidromous animals move upstream to different adult habitats at different elevations | Suitability weighted classes based on the site elevation where species occur from the statewide information in the DAR Aquatic Surveys Database. |
| | Distance Inland | Amphidromous animals move inland to different adult habitats at different distances from the stream mouth. | Suitability weighted classes based on the distance inland of the site where species occur from the statewide information in the DAR Aquatic Surveys Database. |
| | Barrier Height | Amphidromous animals have different abilites to surmount instream barriers. Barriers will prevent species from moving further upstream and occupying suitable habitats. | Suitability weighted classes based on the maximum downstream slope of the site where species occur from the statewide information in the DAR Aquatic Surveys Database. |

Figure 22. Schematic of the stream segment spatial scale including variables used in the model to predict species occurrence within an area of the stream.

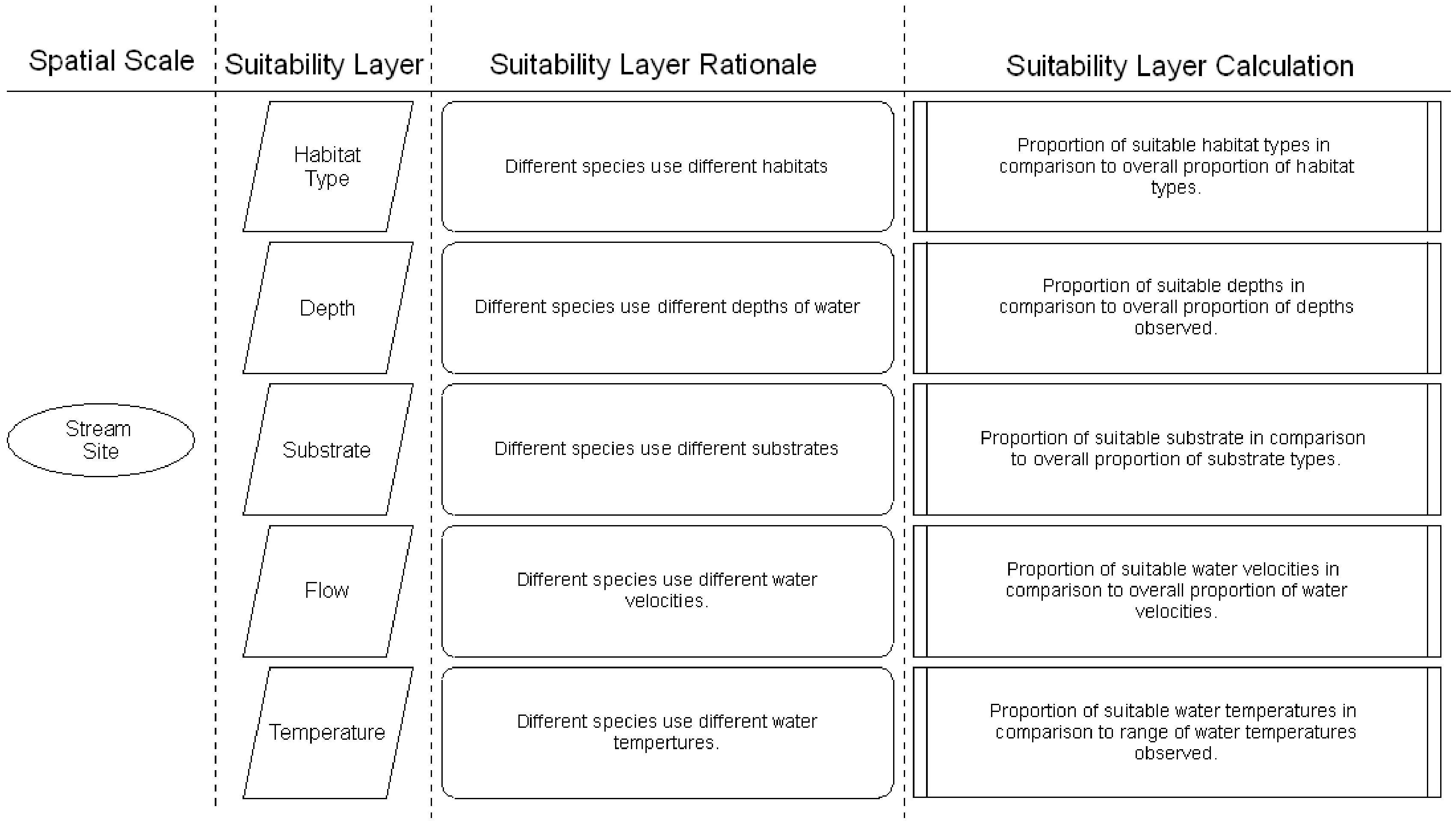


Figure 23. Schematic of the stream site spatial scale including variables used in the model to predict species density within an individual site in the stream. In the HSHEP model presented here, the USGS IFIM results of the East Maui stream replaces the general statewide information as the results for species habitat use and availability for depth, substrate, habitat type, water velocities, and temperature were already developed for these specific streams. General depth information is presented and used as a comparative metric for the suitability of individual sites in the point quadrat surveys.

4) Description of distributional and habitat suitability indices

One of the goals of developing useful metrics in the Habitat Evaluation Procedure was to have a positive linear relationship between the prediction variable and the actual occurrence of the animal. For the watershed variables, a linear regression was used to describe the relationship between the prediction and the actual data. The following set of figures show the relationship between the occurrences of native stream animals with different predictive variables. The relationships show the calculated or predicted variable score (x–axis) in comparison with the proportion of samples from actual field surveys that fall within different groups.

The following figures use data collected statewide (Division of Aquatic Resources 2009). The majority of these data come from DAR point quadrat surveys conducted over the past 20 years (Higashi and Nishimoto 2007). This provides the HSHEP model with over 8000 different survey locations in which to develop the relationships. As additional field information is gathered the model will easily incorporate the new information to improve the predictive quality of the model output.

Watershed and stream level variables:

Figures 24 – 33 show the relationship between individual watershed variables and each species.

Figures 34 – 41 show the watershed suitability indices developed for each species.

Stream segment level variables:

Figures 42 – 47 show the relationship between individual stream segment variables and each species.

Figures 48 – 55 show the segment suitability indices developed for each species.

Site level variables:

Figure 56 show the zones (upstream and downstream of diversions) in the stream of concern on East Maui.

Table 3 reports the expected change in site habitat availability in response to the amount of water diverted based on USGS model estimates.

## Final HSHEP model construction:

The final model combines the information in a spatially-explicit model to predict changes in the habitat as a result of stream diversions. The models reflect the quality of the whole stream and its watershed, the location in a stream and the presence of any downstream barriers, changes in local habitat with respect to water diversion, and the loss of animals due to entrainment in the stream diversions.

To create a final HSHEP model for the East Maui Streams a number of steps were required. The process followed the same steps for each species independently. The following describes the process for a single species.

1. The predicted values for the watershed and stream scale model were determined using the modeled relationship for the 430 watershed used in the analysis.
2. Each value was standardized so that the range of all values had a minimum value of 0 and a maximum value of 1. This resulted in a comparable range of values for each species among the streams in the state.
3. The first two steps were repeated for the stream segment scale relationships so that the minimum value for all segments statewide was 0 and the maximum was 1 for each species. This resulted in a comparable range of values for each species among the stream segments in the state.
4. The resulting values for each of the relationships (watershed and stream segment) were appended to separate 10 m grids of the Hawaiian Islands in ArcGIS.
5. Each grid was weighted by the $r^2$ value for the linear relationship developed for the species.
6. The grids for each scale were multiplied together in ArcGIS into a multi-scale habitat suitability grid.
7. The GIS layer for DAR streams was converted from vector to grid format and all non-stream cells were set to 0 and all stream cells were set to 1 in ArcGIS.
8. The multi-scale habitat suitability grid was multiplied by the stream grid to remove non-stream cells from the analysis in ArcGIS.
9. The resulting range of values for the multi-scale habitat suitability grid was again range standardized so that the minimum value for grid cells statewide was 0 and the maximum was 1 for each species.

At this point, we have combined and range standardized the watershed and stream scale model with the stream segment scale model and have the values for habitat suitability for each 10 m cell of 430 streams statewide. For each species, there values for the habitat units range from 0 to 1 to reflect suitability.

To combine this with measure of site scale habitat suitability created by the USGS in their study on East Maui streams (Gingrich and Wolff 2005), additional steps were followed.

10. The streams were separated into segments with respect to their position either upstream, between, or downstream of a stream diversion (Figure 56).
11. The total amount of Habitat Units was calculated for each segment. This value would be the non-diverted estimate of “naturally available habitat units.” The value unit of measure was in linear meters of stream habitat
12. The estimated value for percent available habitat for each stream segment was gathered from the USGS study (Table 3) and was multiplied with all habitat units within the segment. For example, if USGS predicted that only 50% of instream habitat remained below a stream diversion, then the total linear meters of habitat units within the stream segment below the diversion was reduced by 50%.

13. Additionally, the extent of habitat units lost to lack of passage or entrainment during passage was estimated for each diversion. In general, the diversions were engineered to capture low to moderate stream flows and results in 100% removal of water approximately 70 to 80% of the time (Gingerich 2005).The removal of 100% of flow blocks upstream passage and entrains downstream moving animals. In our model we used 80% as some blockage or entrainment would still occur as a portion of the total flow overtopped the diversion and flowed downstream. As a result the suitability of habitat is decreased by 80% with each crossing of a diversion to get to the habitat (Table 3).
14. For each species in each stream, the estimated total amount of habitat units and the amount lost to a decrease in instream habitat and animal passage issues was calculated.
15. A total value for the combined amount of habitat units for all species was created by adding the individual values for each species. No weighting was on individual species was applied.

## HSHEP model validation:

Validation is an important part of any model building process. The USFW HEP manual provides specific guidance to the HEP model validation process (USFW 1981c). The process has four steps of validation with each step building on the prior step and resulting in higher confidence in the model predictions.

### Step 1. Review by author:

The development of the HSHEP model has been an outgrowth of many years of prior research. The general multi-spatial model for Hawaiian streams was first presented by Parham (2002) and has since been expanding upon by Kuamo’o et al (2007) and Parham (2008). The general concept for the multi-spatial model is relatively straightforward. The observed assemblage of species in a given site is a reflection of conditions in the site, the sites location (e.g. elevation, distance inland, presence of downstream barriers) within the stream, the overall conditions of the stream and its watershed, and proximity of the stream to other productive streams. The concept of scale in ecology (O’Neill et al. 1986, Levin 1992) and hierarchical stream habitat descriptions (Frissell et al. 1986) is generally accepted as important in understanding habitat quality.

The authors of the HSHEP feel that the model reflects observed conditions in Hawaiian Streams and accounts for most major physical factors that influence the presence of amphidromous stream animals. Therefore, we feel that validation at step one is considered complete.

### Step 2: Analyze with sample data:

In the development on many HEP models, extensive data on the habitat requirements of the species of concern is not always available and thus the reliance on expert opinion is necessary. When this path is used in the model development, testing and validation of the model with real or hypothetical data is needed to verify that the output of the model reflects expected patterns (USF&W 1981).

In the development of the HSHEP model we relied heavily on the data stored in the DAR Aquatic Surveys Database. We used data collected on streams statewide in over 8300 different survey locations. Over 90,000 different observations of stream animals were included in the database and the data covered historical state surveys as well as over 200 peer-reviewed papers or technical reports. As a result, the HSHEP is based on the accumulated efforts of all available stream studies and is not just the product of a single survey effort.

The authors of the HSHEP feel that use of data from the largest database of Hawaiian stream animal information make the results of the more widely applicable to predicting habitat suitability in Hawaiian streams. Therefore, we feel that validation at step two is complete.

### Step 3: Review by a species authority:

The HSHEP model is currently in this phase of validation. We have internally reviewed the model and report. The next step is to subject the HSHEP model to wider peer-review by experts in Hawaiian stream ecology. Although we have begun this process, at this time we do not have reviews back from our first group of outside reviewers.

Additionally, we plan on publishing the *Atlas of Hawaiian Stream Animals* in the near future. This will provide species by species accounts and will include the suitability criteria to be used in the HSHEP model. Although we provided substantial amounts of information within this report, we feel publication of distribution and habitat used information in the *Atlas of Hawaiian Stream Animals* will provide a more coherent method of documenting the information and allow for a more directed review of the suitability criteria.

While there are considerable amounts of expertise of Hawaiian stream species in the authorship of this report, we feel that the HSEHP is not fully validated at this level.

### Step 4: Test with field data:

The validation of the newly created HSHEP model with field data is just beginning. The data used to develop this model did not include the recent surveys by DAR on the East Maui Streams. Exclusion of the recent Maui survey data was done for three reasons. First, we did not want to create a circular argument with the model following the logic, “We collected the data on East Maui Streams, made the model using the data, and then predicted conditions based on the data that was used to create the model.” Instead, we tried to use a wide range of data including historic information from East Maui Streams, then we created a model of based on the large dataset, and then finally we compared the results with the conditions observed in the recent surveys. Second, we used the same data set that was used to create the *Atlas of Hawaiian Watersheds and Their Aquatic Resources* (Parham et al. 2008). This provides documentation of the information used to create the HSEHP model. Finally, we wanted to compare the results of the recent Maui stream surveys with the model predictions. The results and conclusion sections of this report do this and suggest that the model is accurately portraying habitat conditions.

An additional note on the status of testing the model with actual field data, we reserved a dataset of the results of several thousand surveys entered into the DAR Aquatic Surveys Database over the past year. These data will be used to provide a statistical validation of the HSHEP model. At the completion of this validation effort, the resulting model will be submitted for publication in a peer reviewed scientific journal. At the completion of this step the model will be considered fully validated.

Given the design of the model, as additional data becomes available that helps describe suitable stream habitat, the data will be readily added to the overall model and will improve predictive accuracy. While full validation has yet to be completed, the HSHEP model has completed the first two steps of validation and is producing results consistent with observed field conditions. Given the large dataset of information from which the model was developed we feel the results of will be useful in guiding wise stream management decisions, yet it is important for managers to understand the validation status of the model.

Watershed and Stream Scale: Watershed and Stream Size Rating

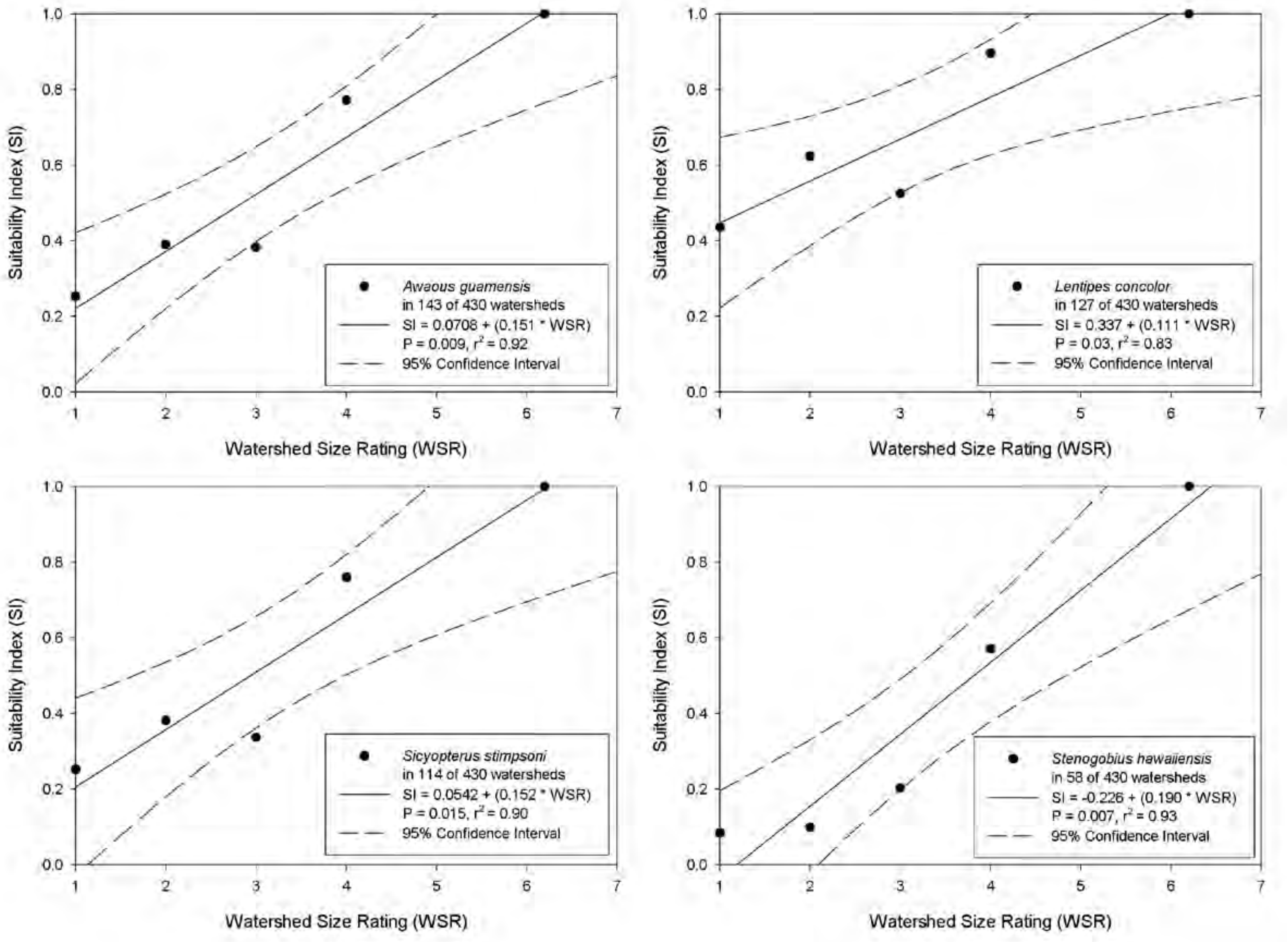


Figure 24. Suitability Indices for Watershed Size Rating for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

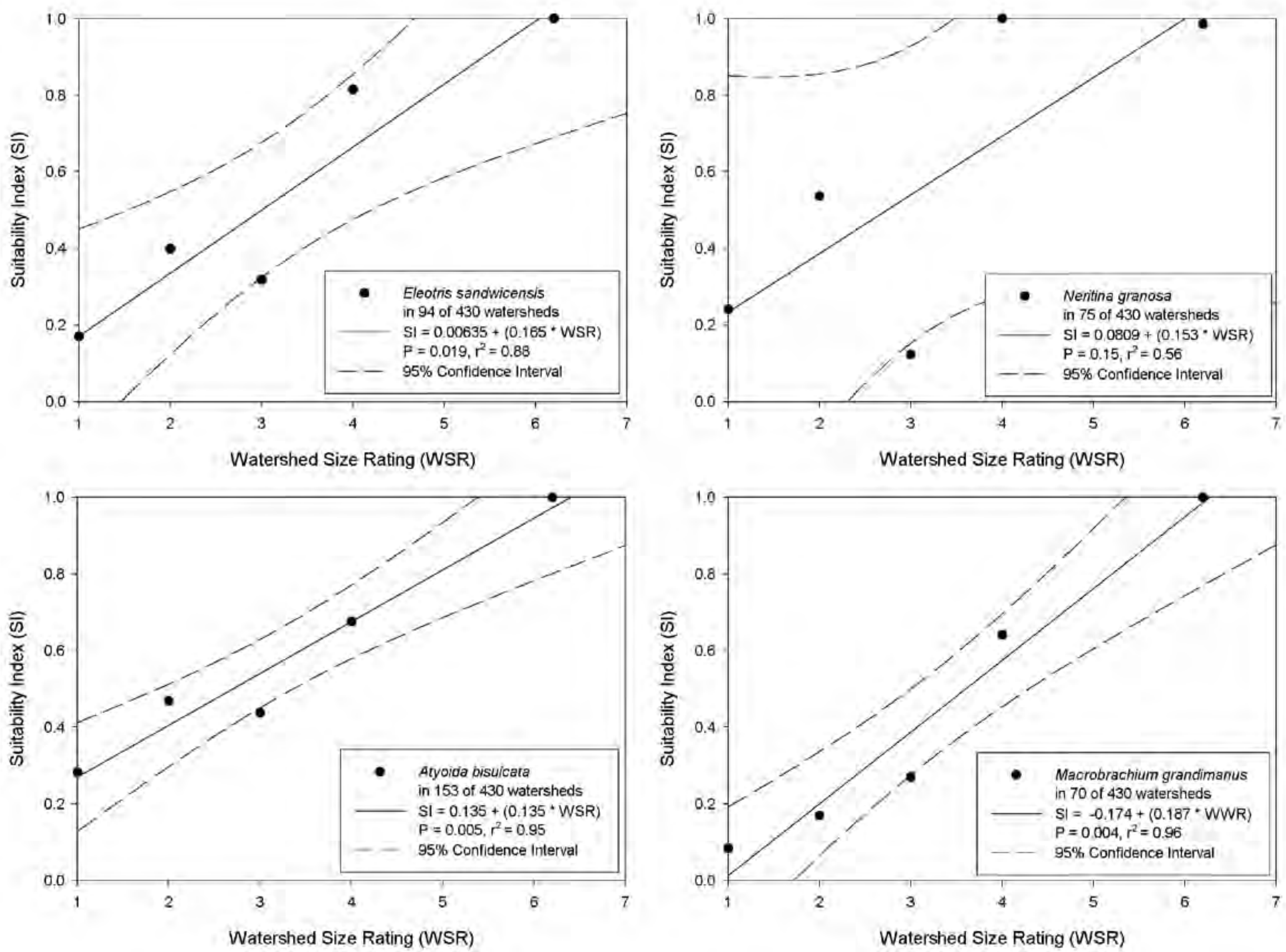


Figure 25. Suitability Indices for Watershed Size Rating for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

## Watershed Wetness Rating

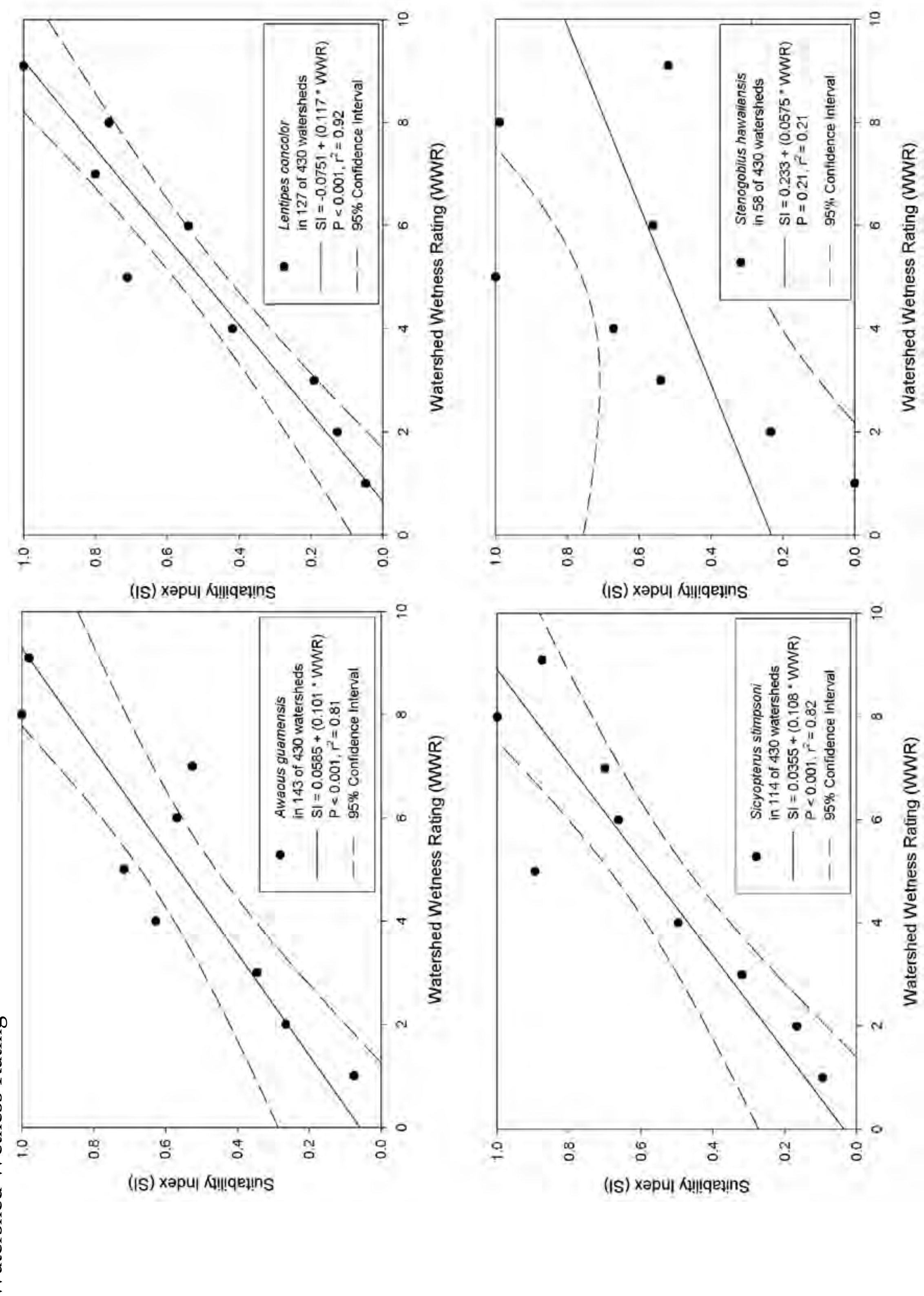


Figure 26. Suitability Indices for Watershed Wetness Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis*.

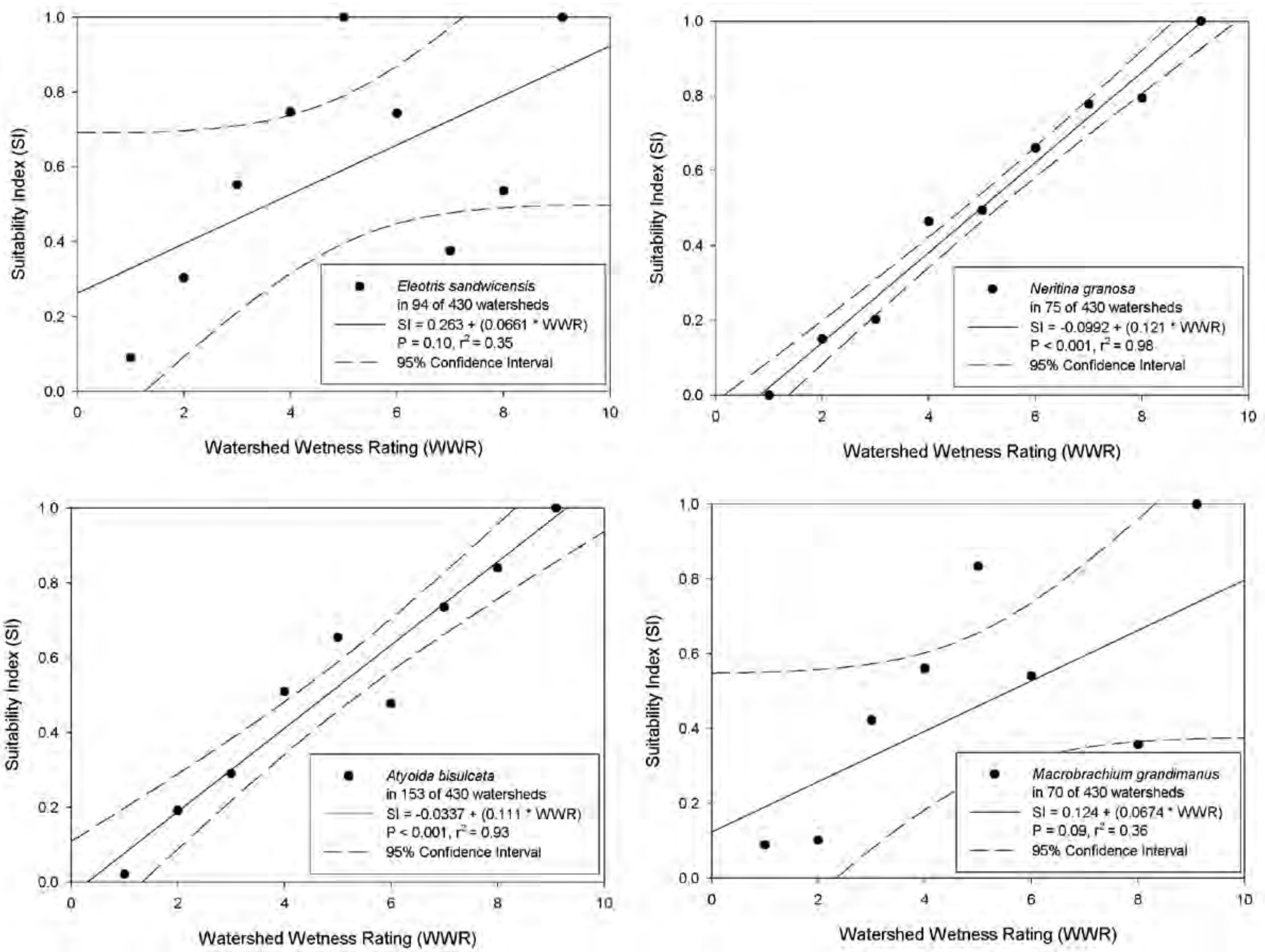


Figure 27. Suitability Indices for Watershed Wetness Rating for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

## Watershed Stewardship Rating

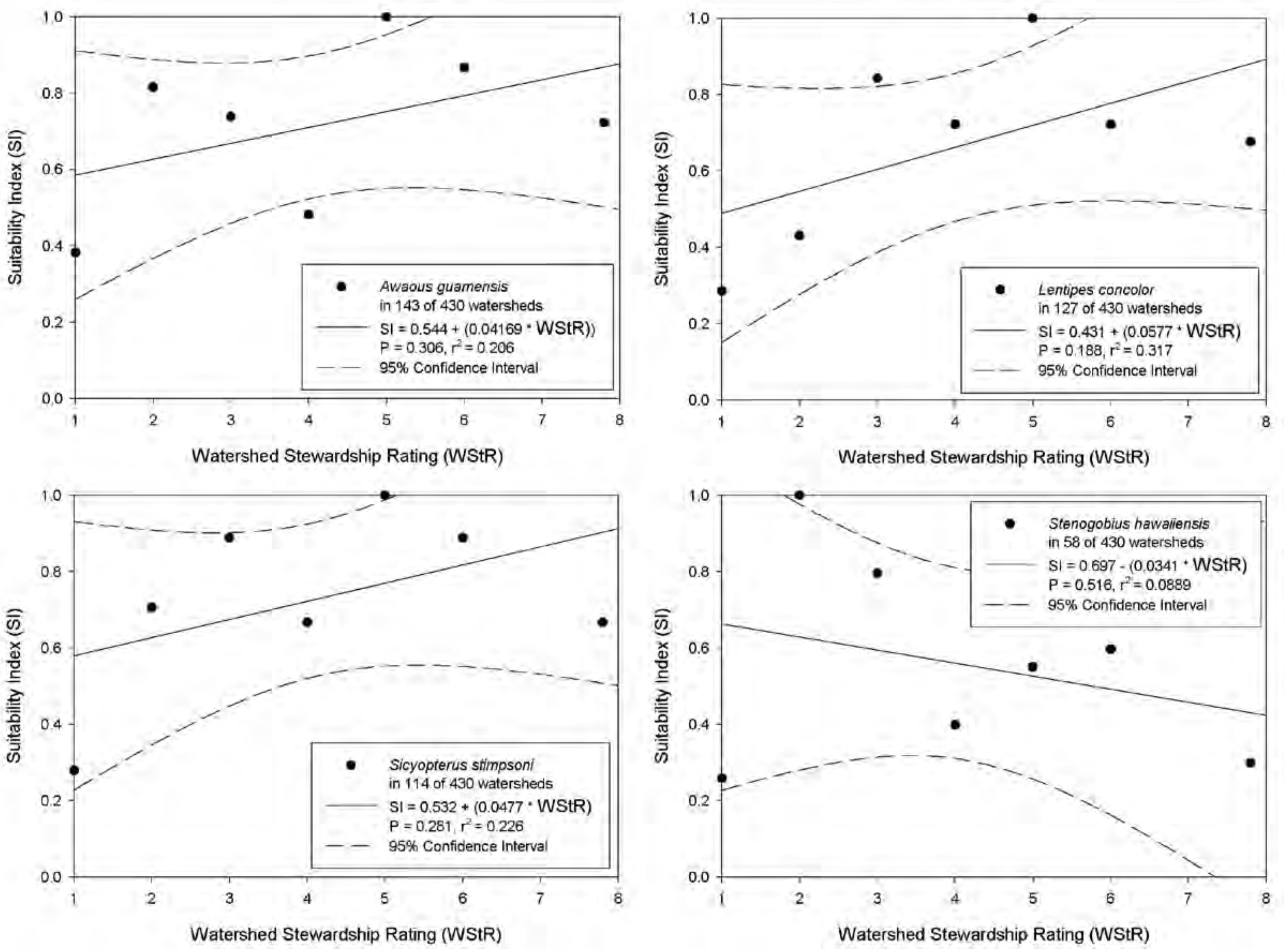


Figure 28. Suitability Indices for Watershed Stewardship Rating for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

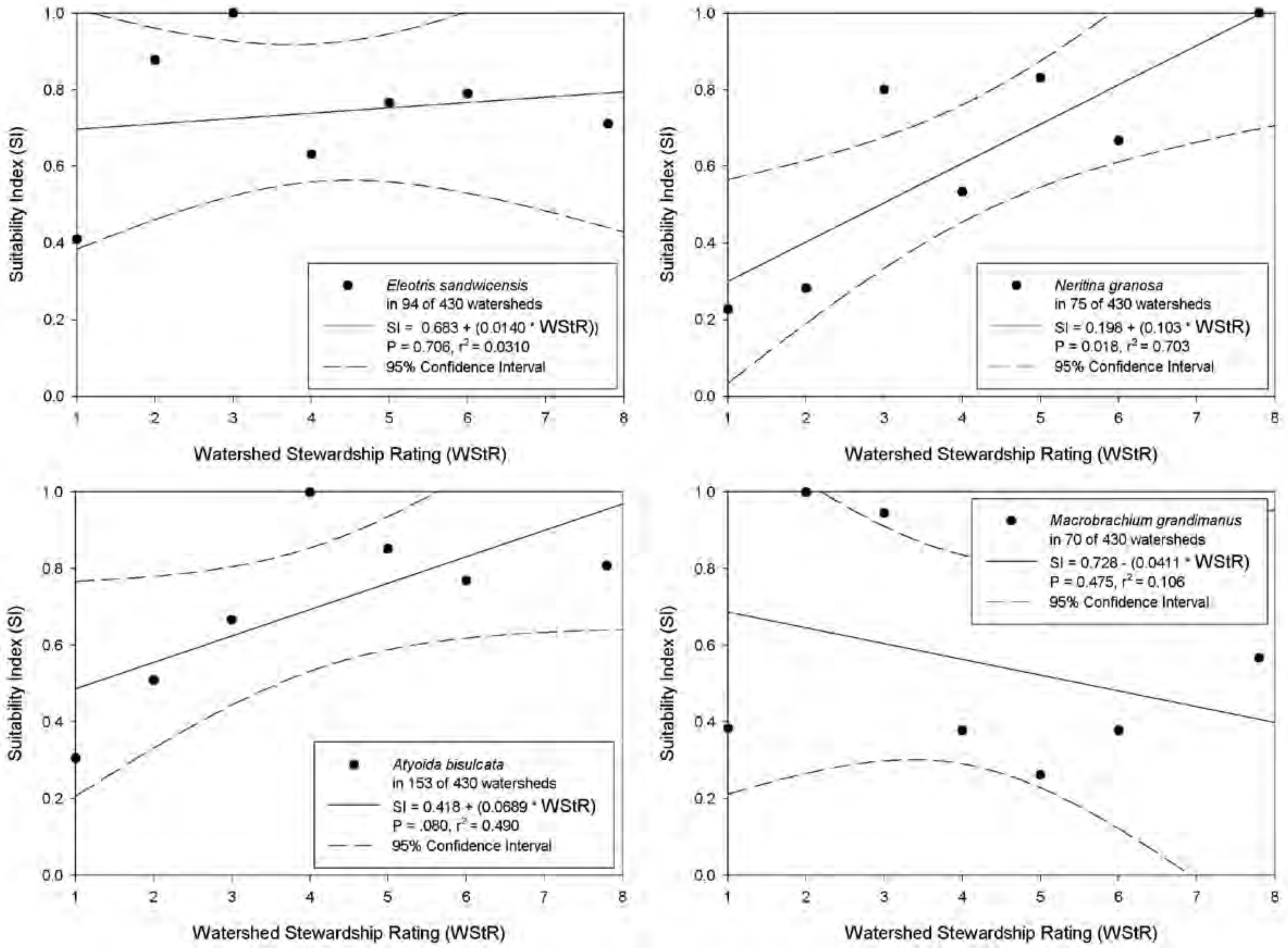


Figure 29. Suitability Indices for Watershed Stewardship Rating for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

## Watershed Estuary and Nearshore Rating

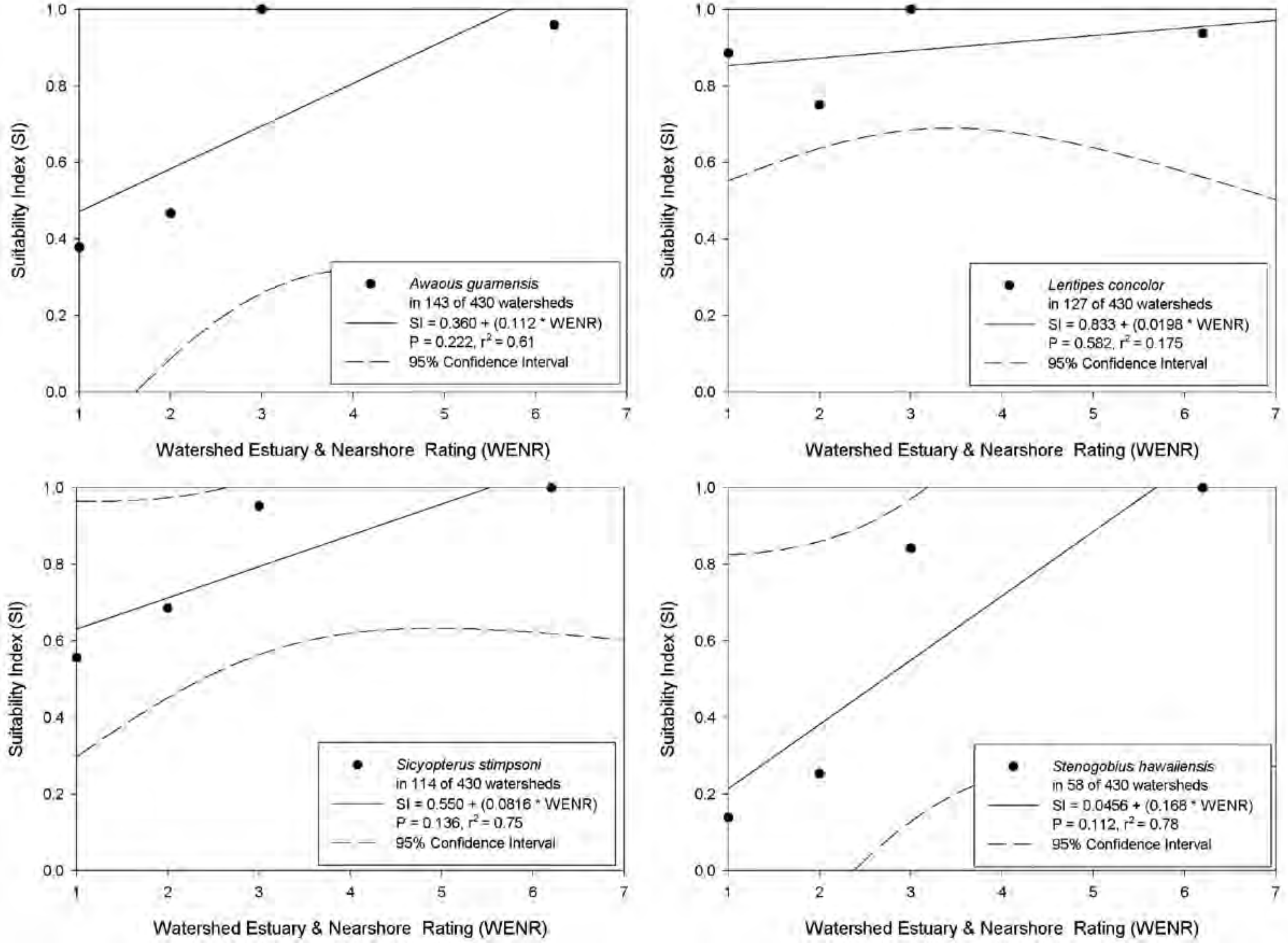


Figure 30. Suitability Indices for Watershed Estuary and Nearshore Rating for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

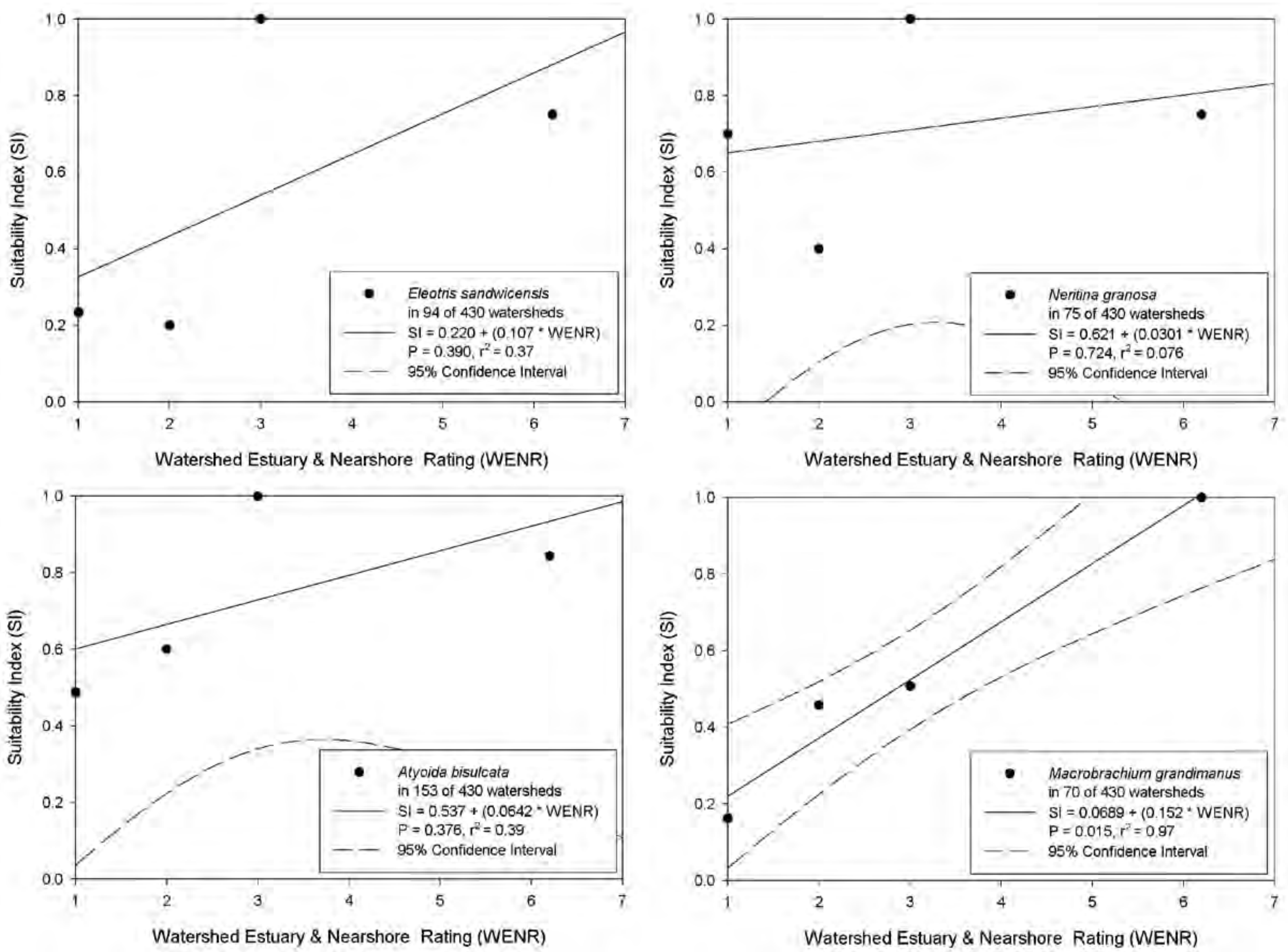


Figure 31. Suitability Indices for Watershed Estuary and Nearshore Rating for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

## Watershed Land Quality Rating

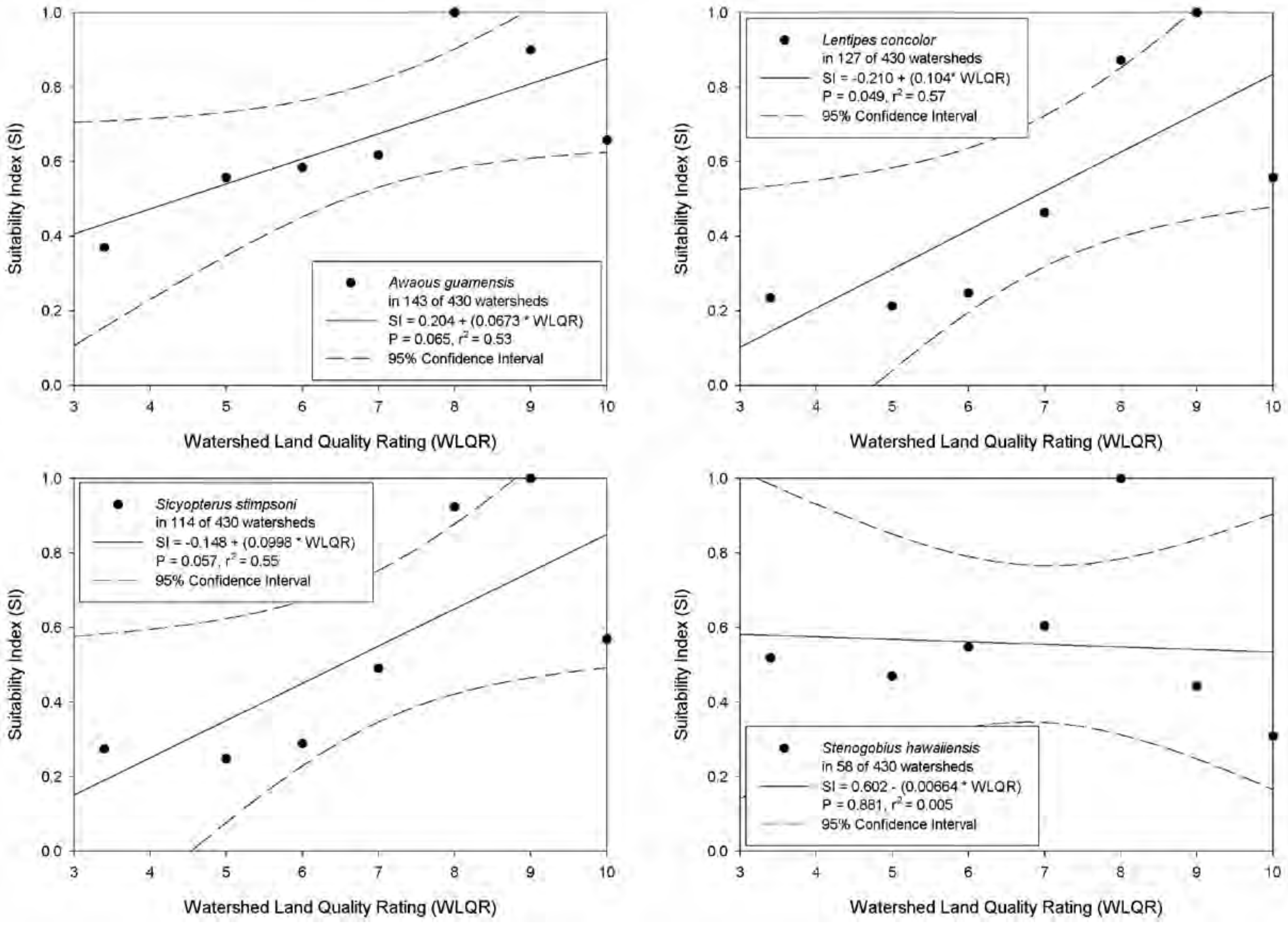


Figure 32. Suitability Indices for Watershed Land Quality Rating for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

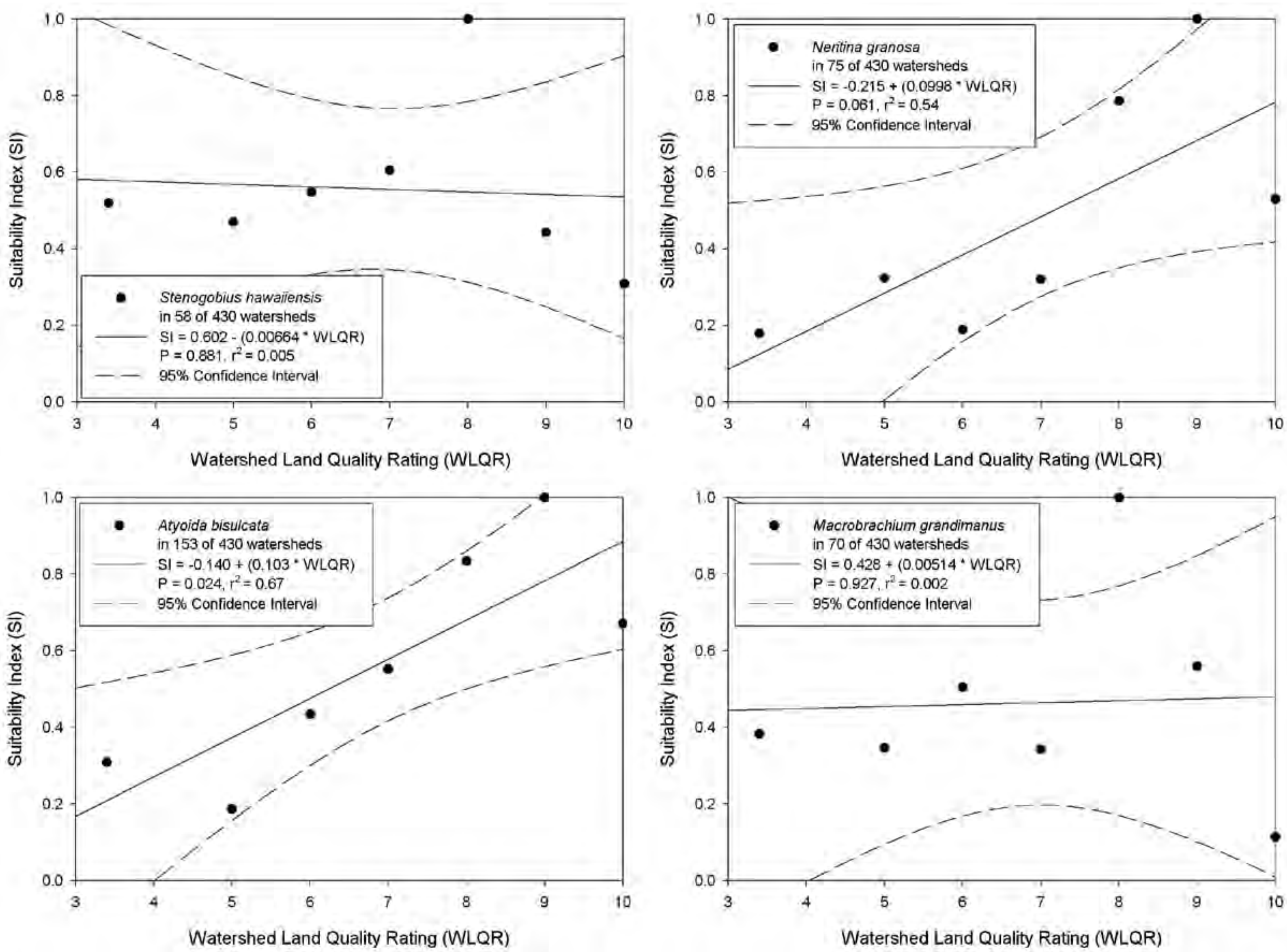


Figure 33. Suitability Indices for Watershed Land Quality Rating for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

Watershed Suitability Models for each species

*Awaous guamensis*:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.043 + (0.425 * \mathrm{WWR}) + (0.543 * \mathrm{WSR}) + (0.280 * \mathrm{WENR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)
WSR = Watershed Size Rating, ($p < 0.001$)
WENR = Watershed Estuary and Nearshore Rating, ($p < 0.001$).

This equation had a Likelihood Ratio Test Statistic of 120.7 (P = <0.001), and correctly predicted the presence or absence of *Awaous guamensis* in 322 of 430 watersheds (74.9 % correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Awaous guamensis*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Awaous guamensis* occurred (Figure 34).

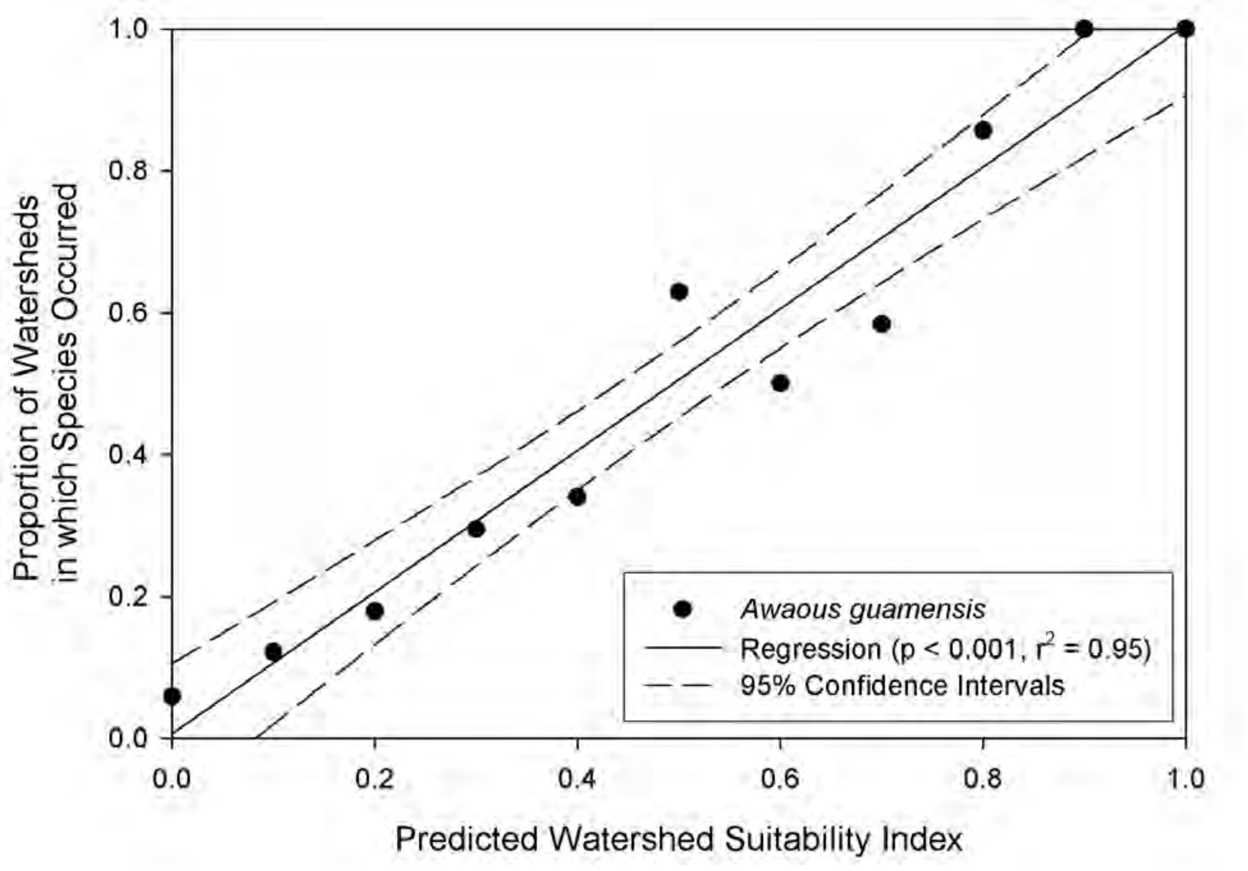


Figure 34. Proportion of the total watersheds where *Awaous guamensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Awaous guamensis*.

*Lentipes concolor*:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(\text{-4.164} + (0.493 * \text{WWR}) + (0.362 * \text{WSR}) + (0.121 * \text{WStR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)
WSR = Watershed Size Rating, ($p < 0.001$)
WStR = Watershed Stewardship Rating, ($p = 0.025$).

This equation had a Likelihood Ratio Test Statistic of 117.8 (P = <0.001), and correctly predicted the presence or absence of *Lentipes concolor* in 322 of 430 watersheds (74.9 % correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Lentipes concolor*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Lentipes concolor* occurred (Figure 35).

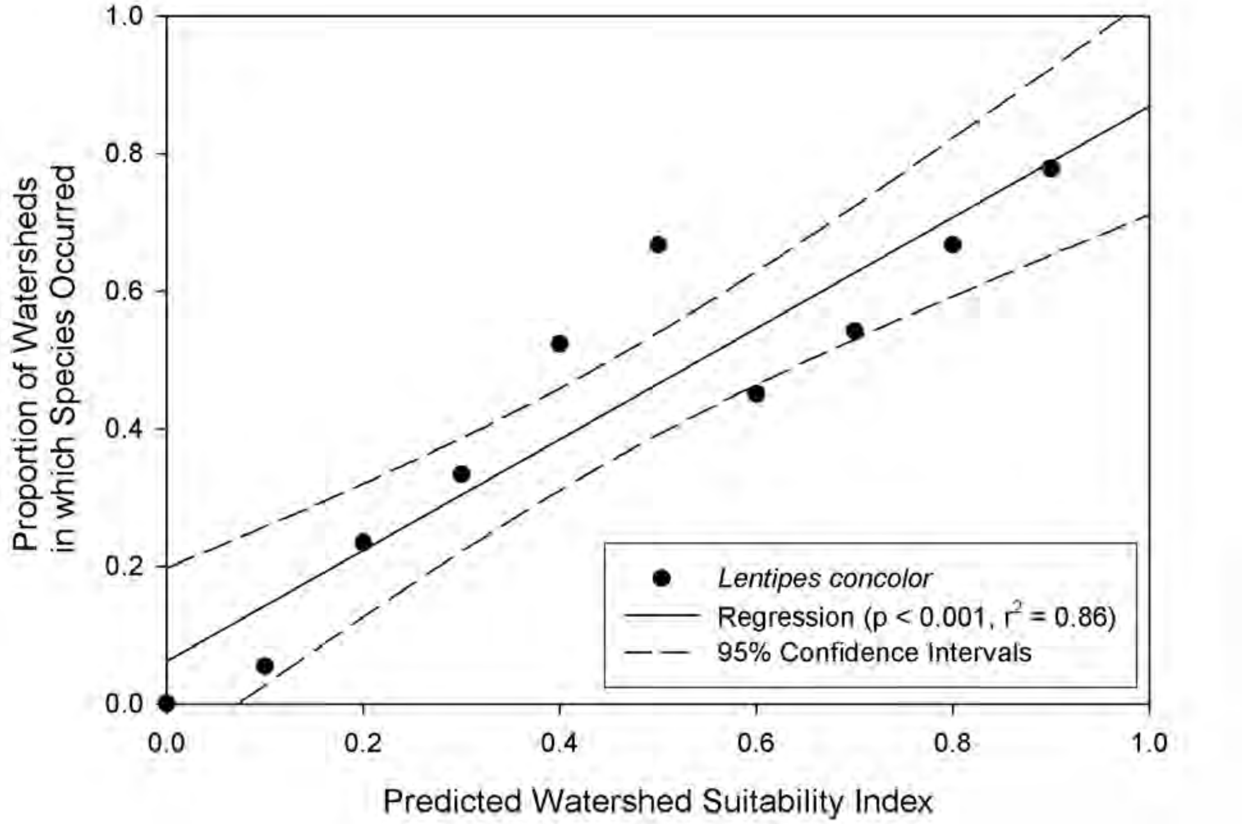


Figure 35. Proportion of the total watersheds where *Lentipes concolor* was observed within each 0.1 group of the Watershed Suitability Index equation for *Lentipes concolor*.

*Sicyopterus stimpsoni*:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.195 + (0.358 * \mathrm{WWR}) + (0.539 * \mathrm{WSR}) + (0.135 * \mathrm{WStR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)
WSR = Watershed Size Rating, ($p < 0.001$)
WENR = Watershed Stewardship Rating, ($p = 0.012$).

This equation had a Likelihood Ratio Test Statistic of 97.1 ($P = <0.001$), and correctly predicted the presence or absence of *Sicyopterus stimpsoni* in 340 of 430 watersheds (79.1% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Sicyopterus stimpsoni*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Sicyopterus stimpsoni* occurred (Figure 36).

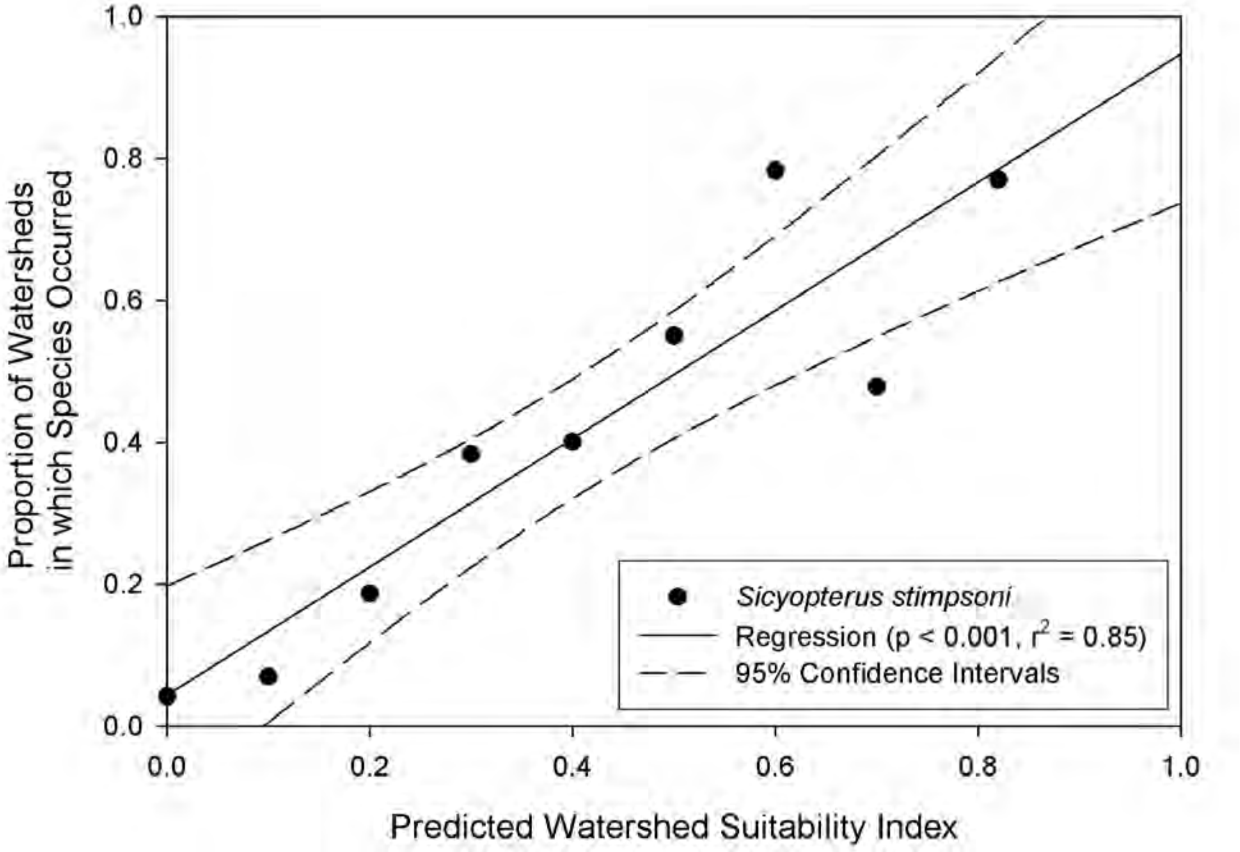


Figure 36. Proportion of the total watersheds where *Sicyopterus stimpsoni* was observed within each 0.1 group of the Watershed Suitability Index equation for *Sicyopterus stimpsoni*.

*Stenogobius hawaiiensis*:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.923 + (0.206 * \mathrm{WWR}) + (0.796 * \mathrm{WSR}))}}$$

where: WWR = Watershed Wetness Rating, ($p = 0.003$)
WSR = Watershed Size Rating, ($p < 0.001$).

This equation had a Likelihood Ratio Test Statistic of 73.4 ($P = <0.001$), and correctly predicted the presence or absence of *Stenogobius hawaiiensis* in 375 of 430 watersheds (87.2% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Stenogobius hawaiiensis*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Stenogobius hawaiiensis* occurred (Figure 37).

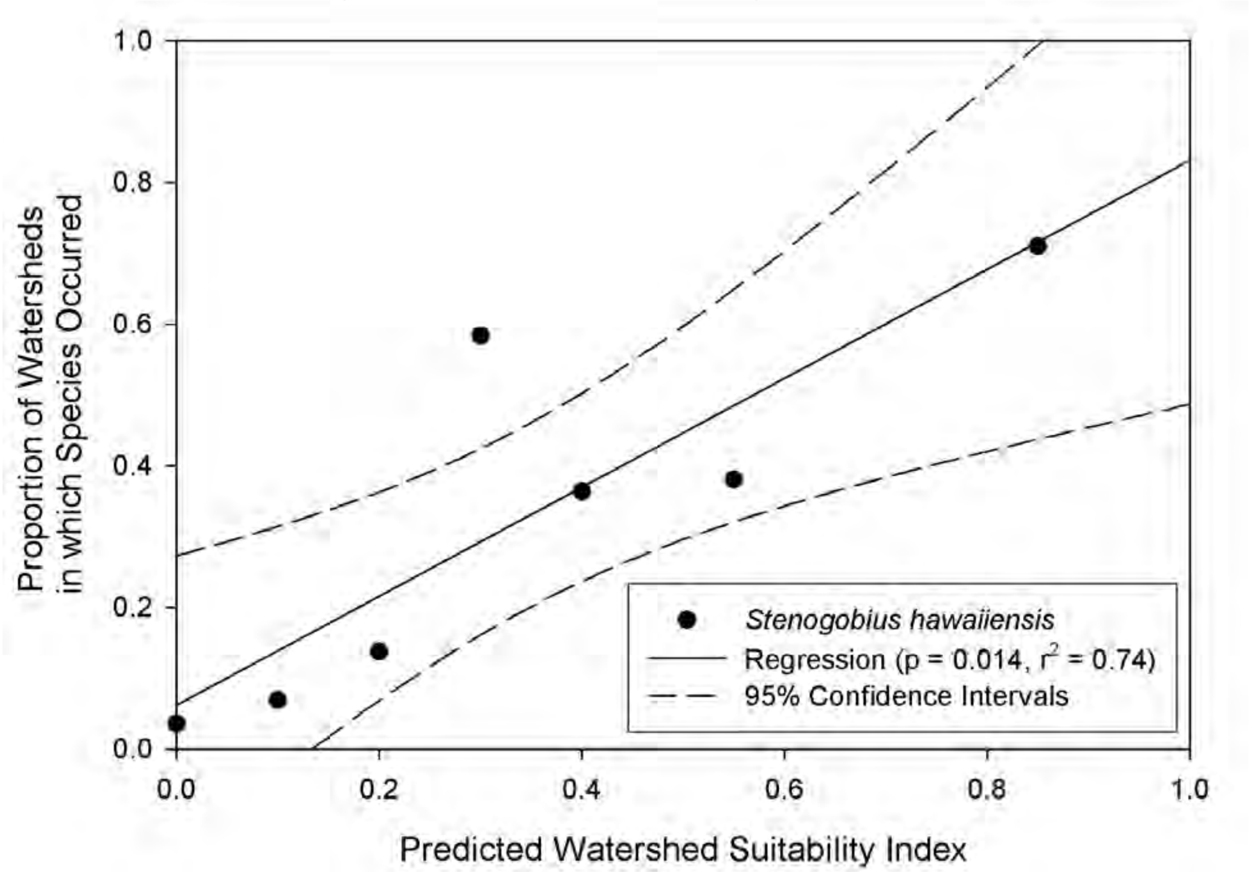


Figure 37. Proportion of the total watersheds where *Stenogobius hawaiiensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Stenogobius hawaiiensis*.

*Eleotris sandwicensis*:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-3.552 + (0.245 * \mathrm{WWR}) + (0.376 * \mathrm{WSR}) + (0.278 * \mathrm{WENR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)
WSR = Watershed Size Rating, ($p < 0.001$)
WENR = Watershed Estuary and Nearshore Rating, ($p < 0.001$).

This equation had a Likelihood Ratio Test Statistic of 65.4 (P = <0.001), and correctly predicted the presence or absence of *Eleotris sandwicensis* in 343 of 430 watersheds (79.8% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Eleotris sandwicensis*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Eleotris sandwicensis* occurred (Figure 38).

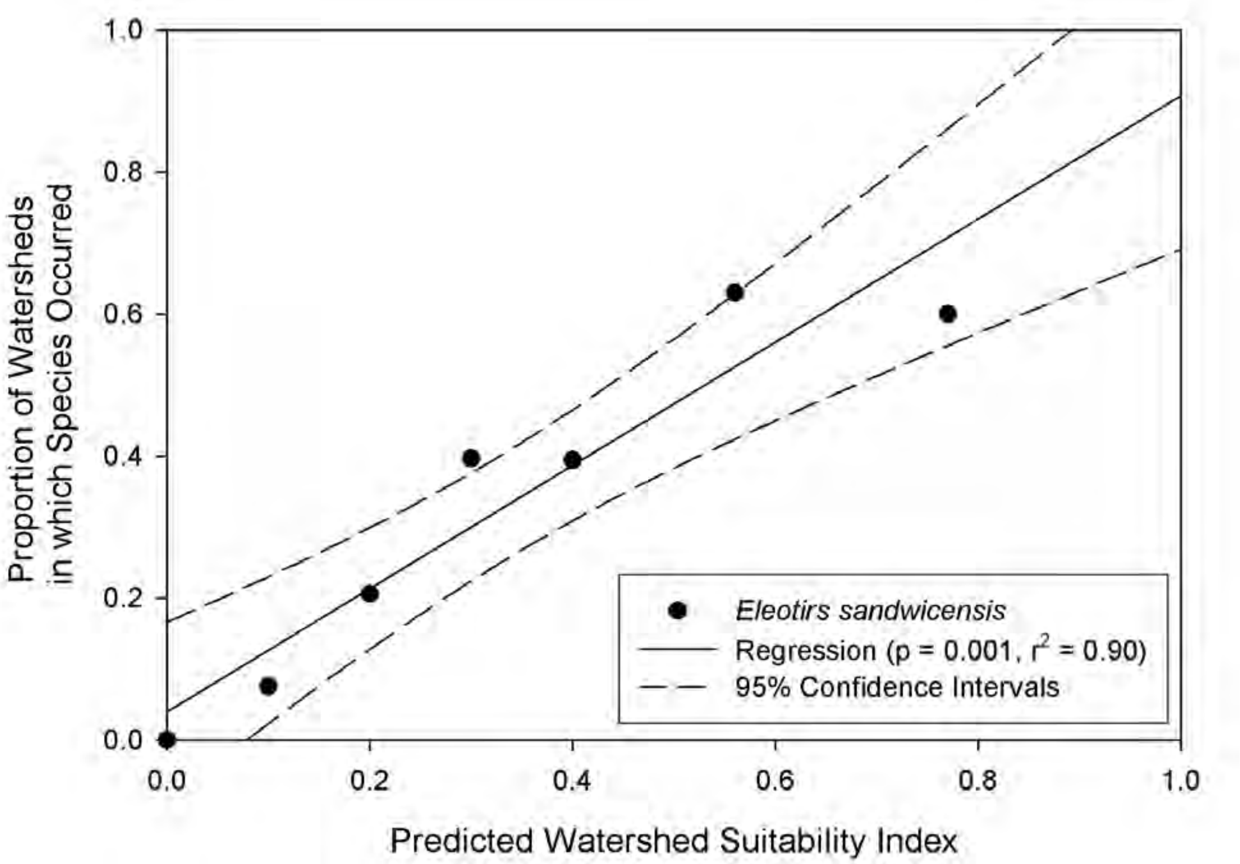


Figure 38. Proportion of the total watersheds where *Eleotris sandwicensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Eleotris sandwicensis*.

*Neritina granosa*:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.806 + (0.375 * \mathrm{WWR}) + (0.435 * \mathrm{WSR}) + (0.177 * \mathrm{WStR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)
WSR = Watershed Size Rating, ($p < 0.001$)
WENR = Watershed Stewardship Rating, ($p = 0.003$).

This equation had a Likelihood Ratio Test Statistic of 77.5 ($P = <0.001$), and correctly predicted the presence or absence of *Neritina granosa* in 357 of 430 watersheds (83.0% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Neritina granosa*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Neritina granosa* occurred (Figure 39).

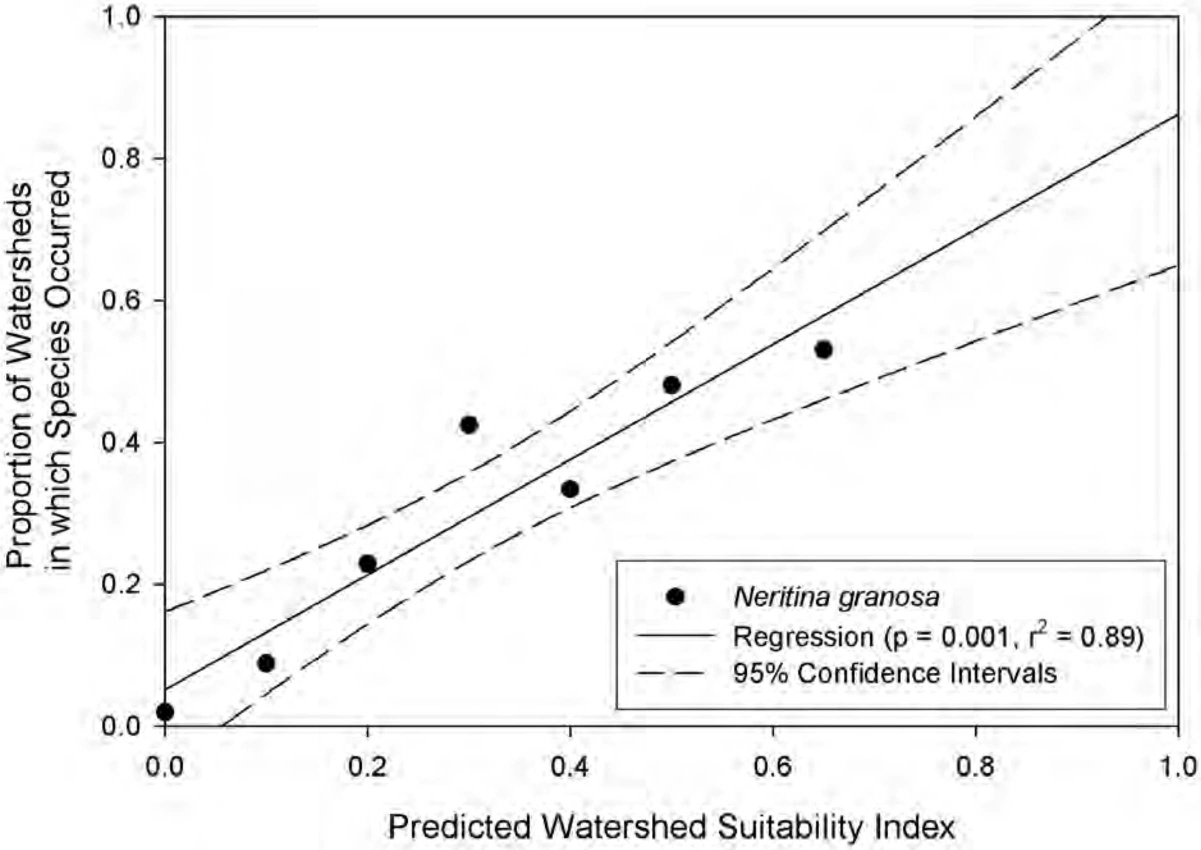


Figure 39. Proportion of the total watersheds where *Neritina granosa* was observed within each 0.1 group of the Watershed Suitability Index equation for *Neritina granosa*.

*Atyoida bisulcata*:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.458 + (0.508 * \mathrm{WWR}) + (0.497 * \mathrm{WSR}) + (0.179 * \mathrm{WStR}) + (0.165 * \mathrm{WENR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)
WSR = Watershed Size Rating, ($p < 0.001$)
WStR = Watershed Stewardship Rating, ($p = 0.001$)
WENR = Watershed Estuary and Nearshore Rating, ($p = 0.04$).

This equation had a Likelihood Ratio Test Statistic of 153.3 ($P = <0.001$), and correctly predicted the presence or absence of *Atyoida bisulcata* in 336 of 430 watersheds (78.1% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Atyoida bisulcata*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Atyoida bisulcata* occurred (Figure 40).

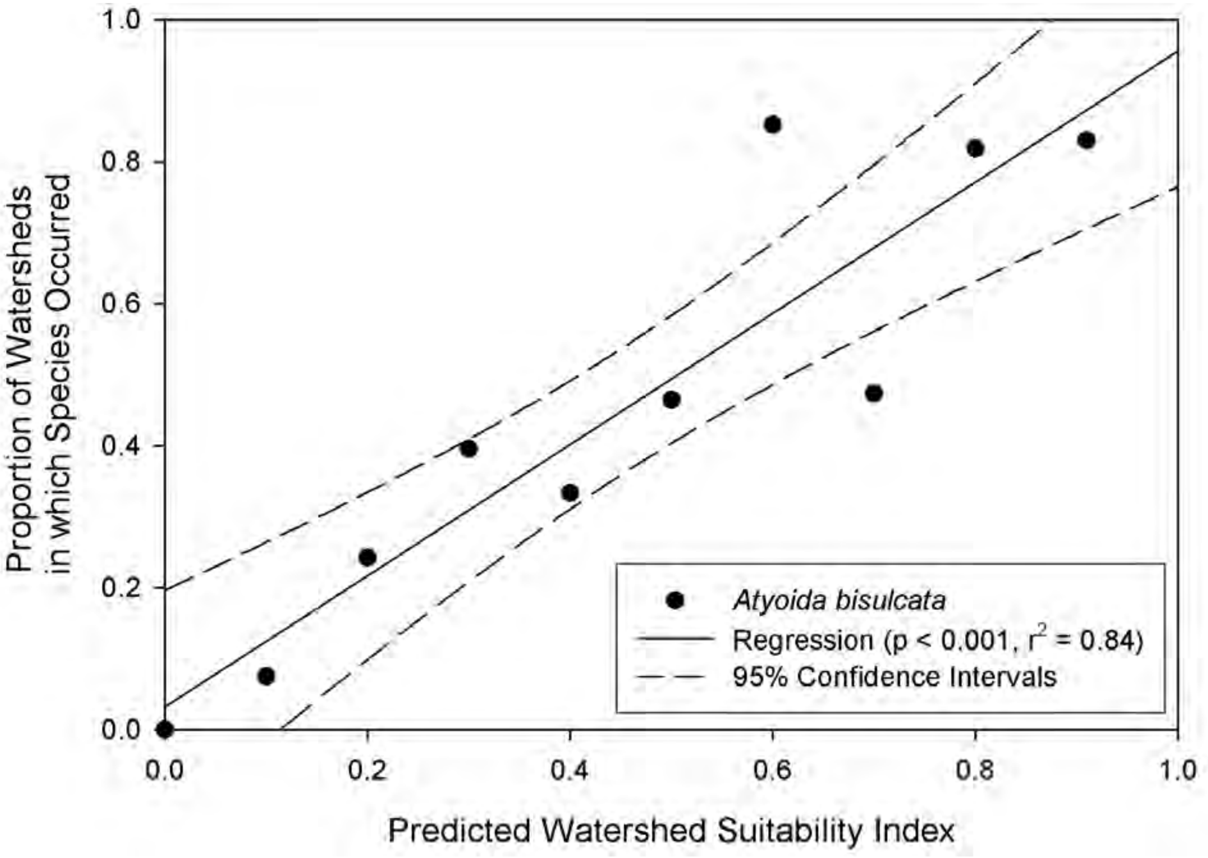


Figure 40. Proportion of the total watersheds where *Atyoida bisulcata* was observed within each 0.1 group of the Watershed Suitability Index equation for *Atyoida bisulcata*.

*Macrobrachium grandimanus*:

The multiple logistic regression equation with the highest prediction accuracy was:

$$P = \frac{1}{1 + e^{-(-4.942 + (0.286 * \text{WWR}) + (0.775 * \text{WSR}))}}$$

where: WWR = Watershed Wetness Rating, ($p < 0.001$)
WSR = Watershed Size Rating, ($p < 0.001$).

This equation had a Likelihood Ratio Test Statistic of 82.4 (P = <0.001), and correctly predicted the presence or absence of *Macrobrachium grandimanus* in 366 of 430 watersheds (85.1% correct) at a probability level of 0.5. To further confirm a positive relationship between the predicted watershed suitability value and the occurrence of *Macrobrachium grandimanus*, the proportion of samples within each 0.1 sized suitability bin was compared for all watersheds and those watersheds in which *Macrobrachium grandimanus* occurred (Figure 41).

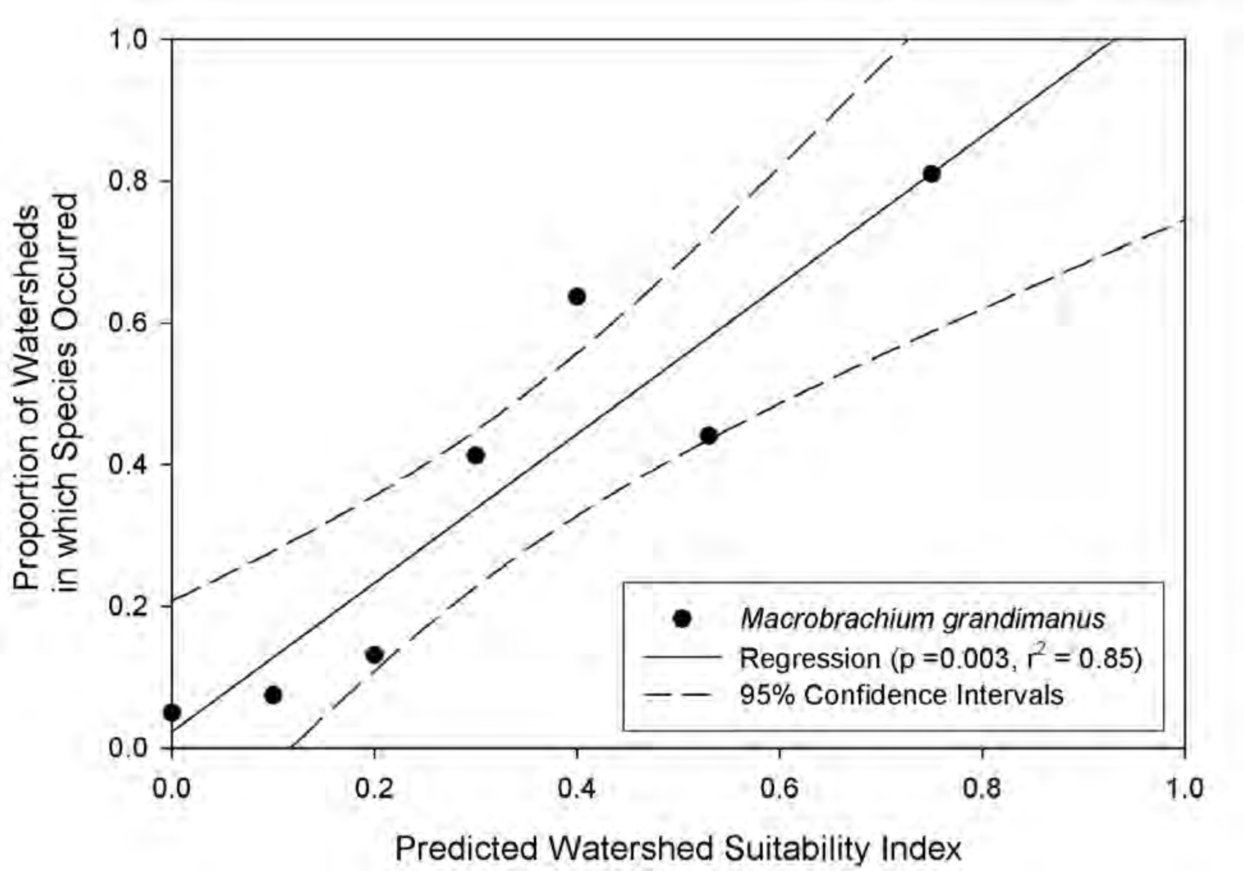


Figure 41. Proportion of the total watersheds where *Macrobrachium grandimanus* was observed within each 0.1 group of the Watershed Suitability Index equation for *Macrobrachium grandimanus*.

### Stream Reach Scale: Elevation Suitability Indices

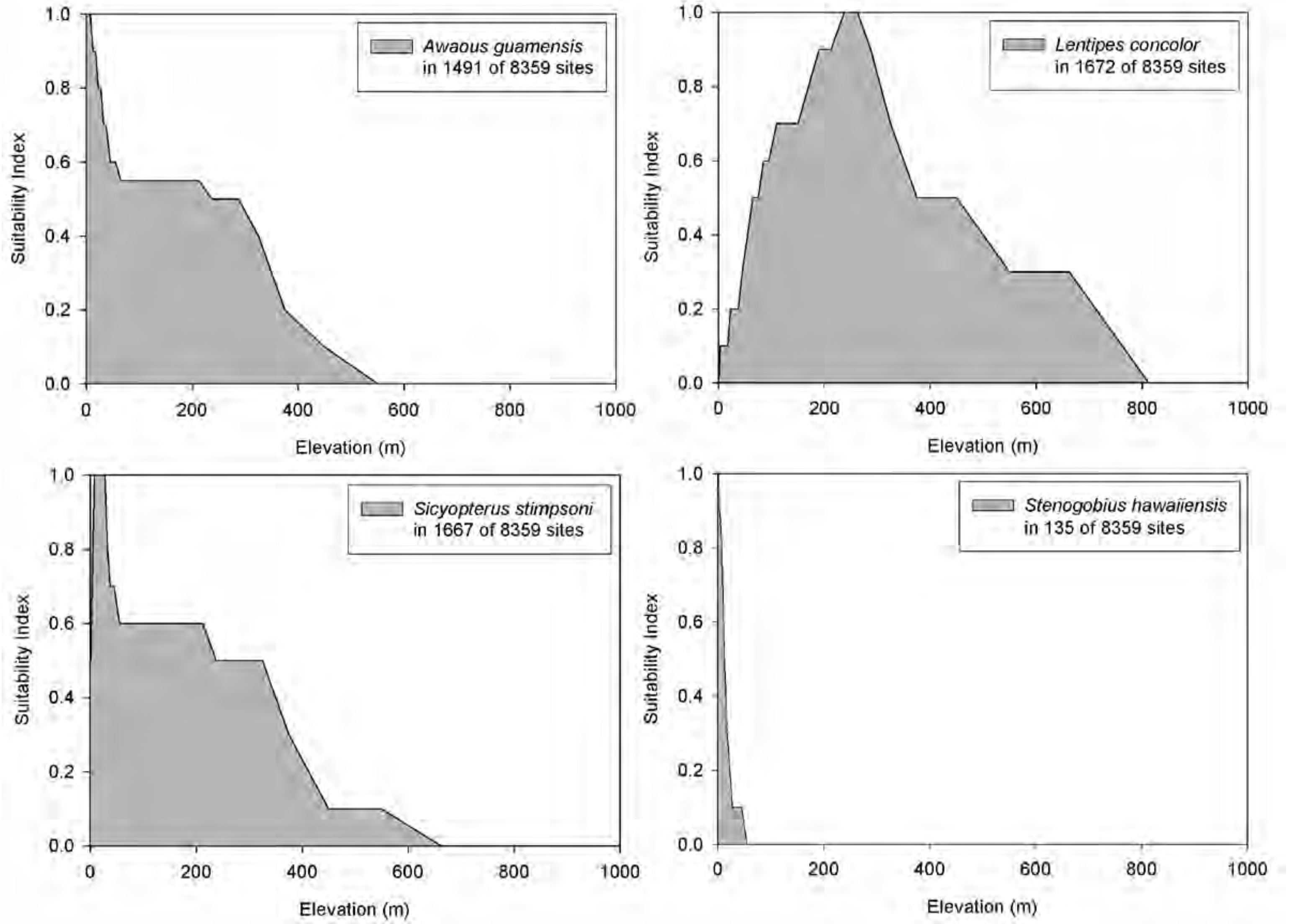


Figure 42. Suitability Indices for Elevation for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

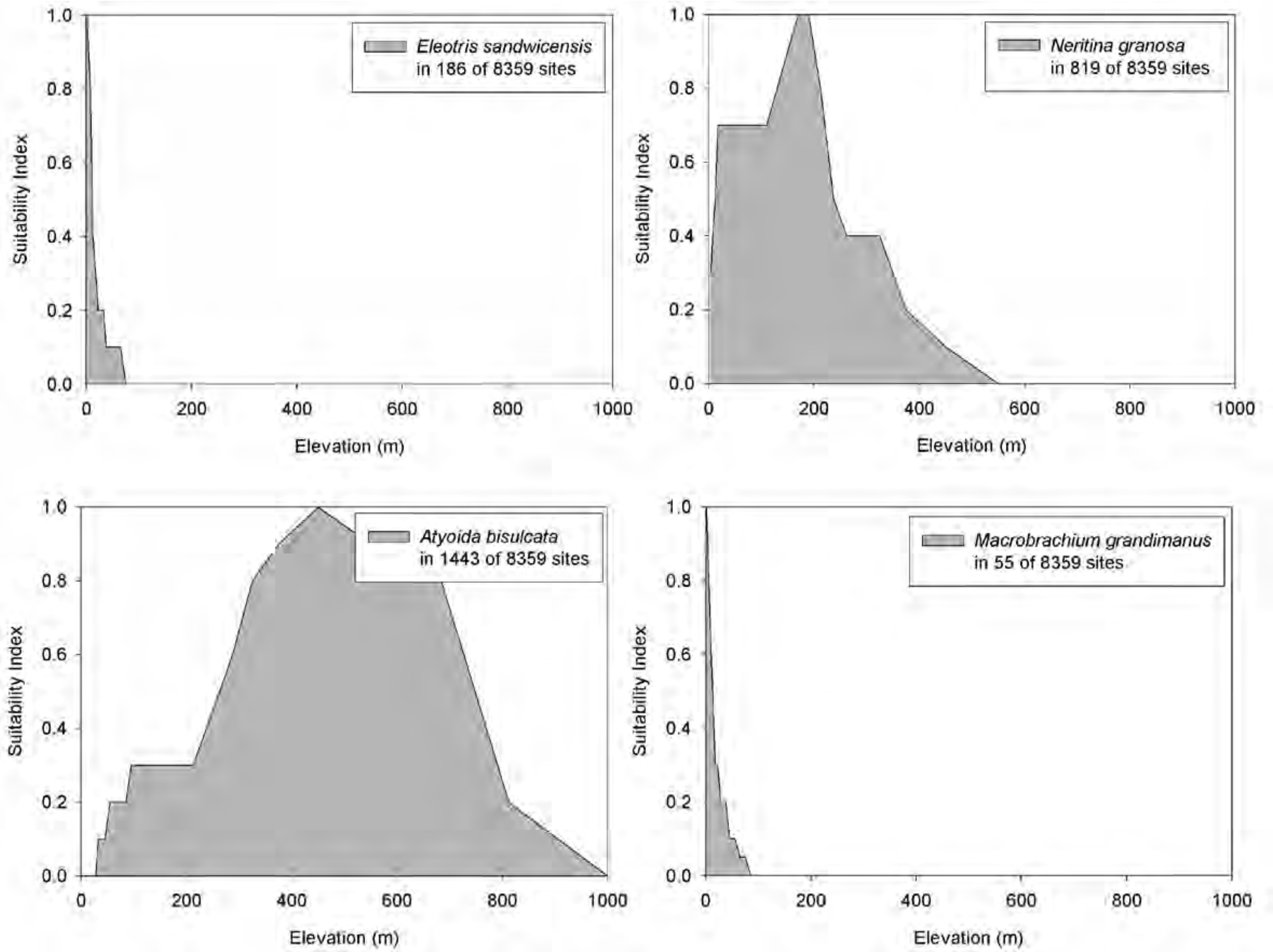


Figure 43. Suitability Indices for Elevation for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

## Distance Inland Suitability Indices

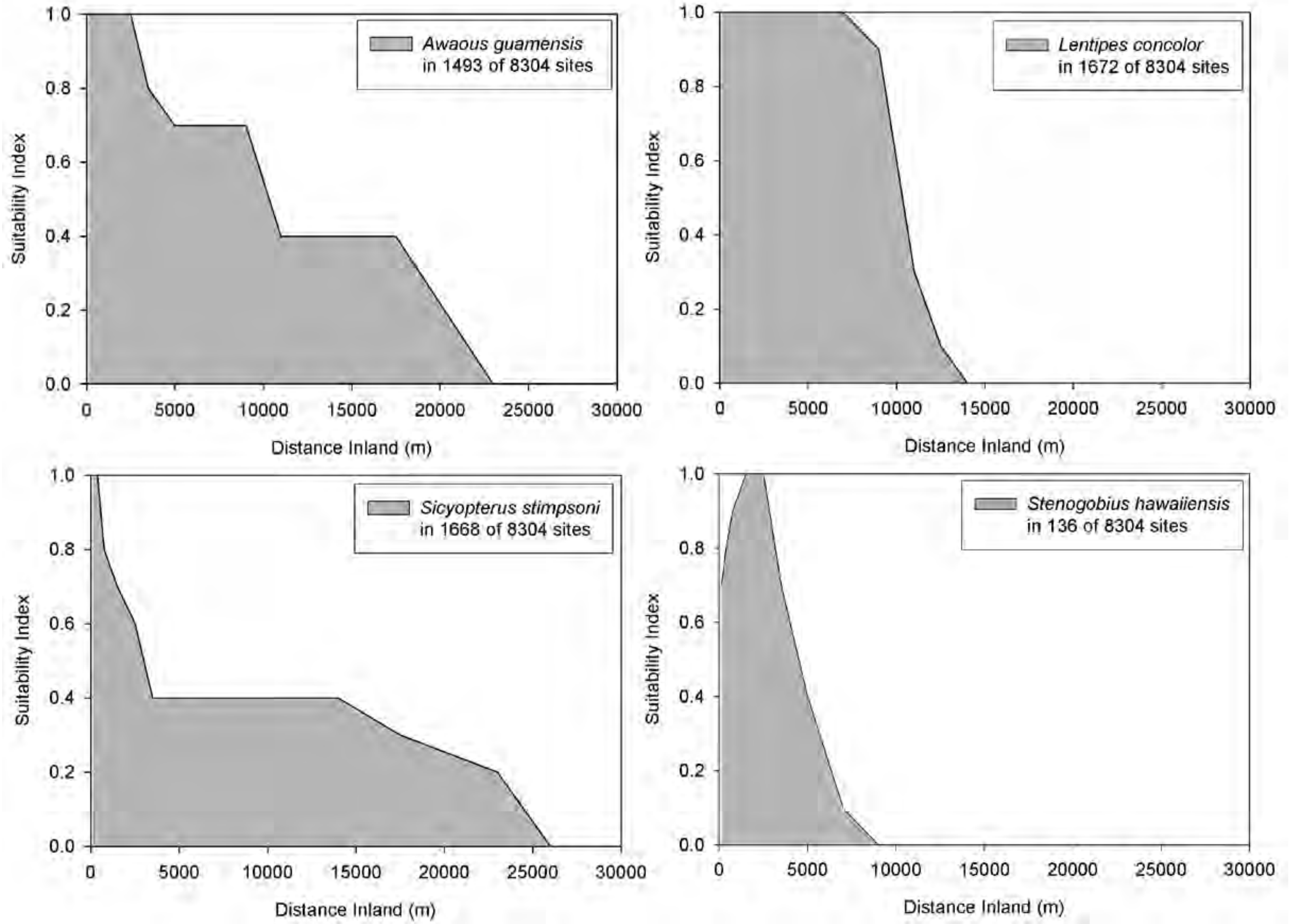


Figure 44. Suitability Indices for Distance Inland for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

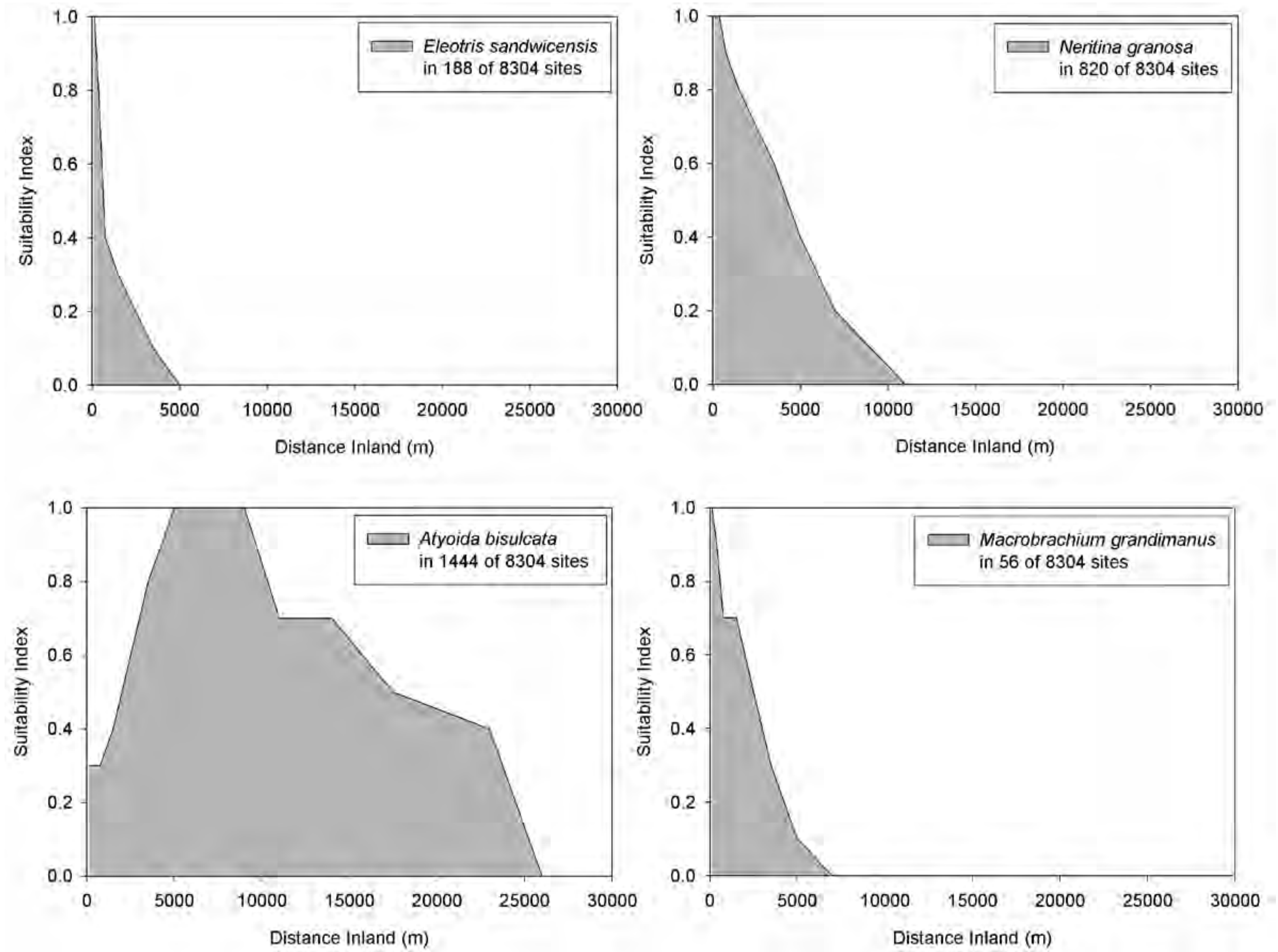


Figure 45. Suitability Indices for Distance Inland for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

Barrier Height Suitability Indices

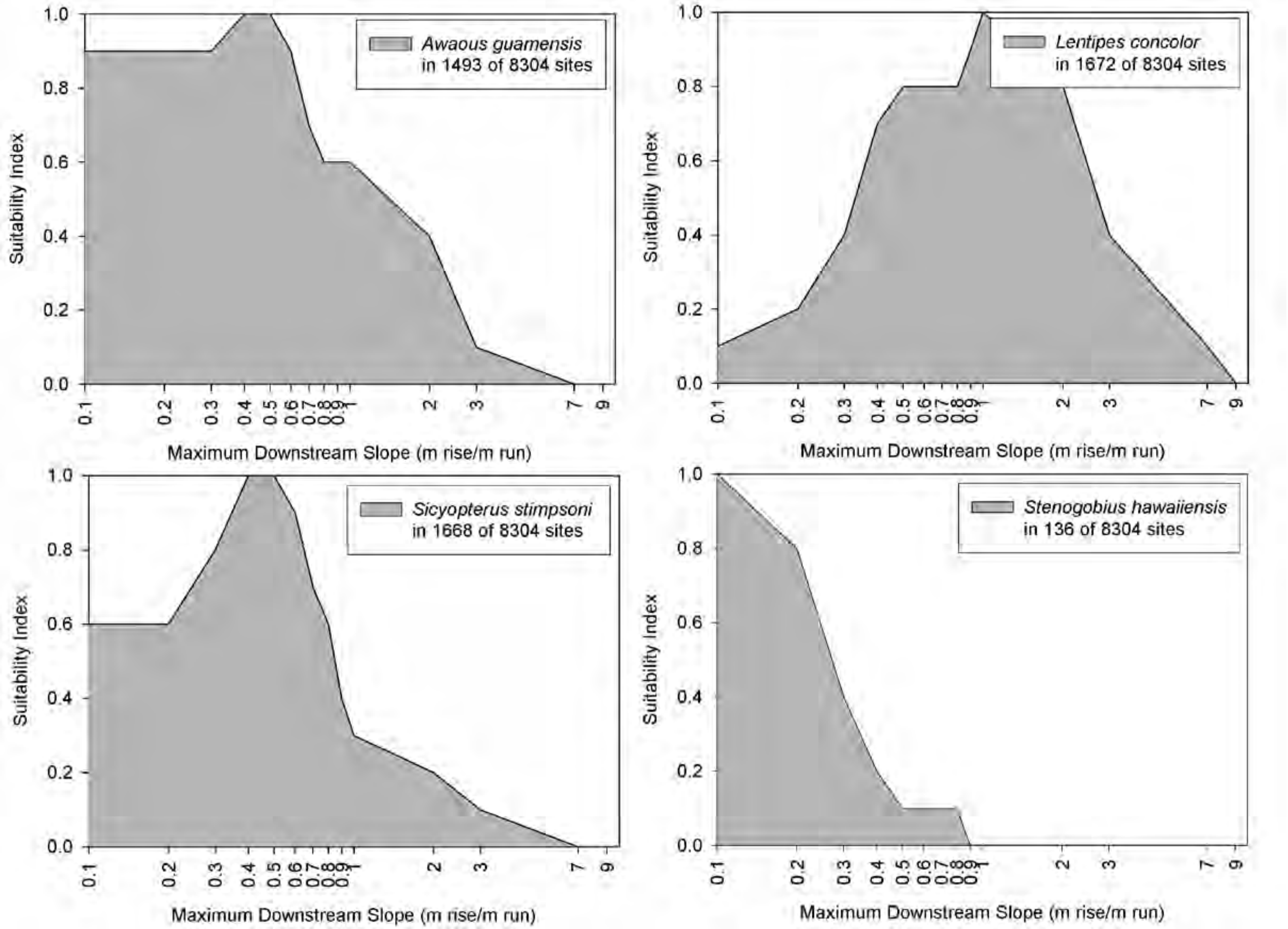


Figure 46. Suitability Indices for Barriers (maximum downstream slope over 10m distance) for *Awaous guamensis, Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

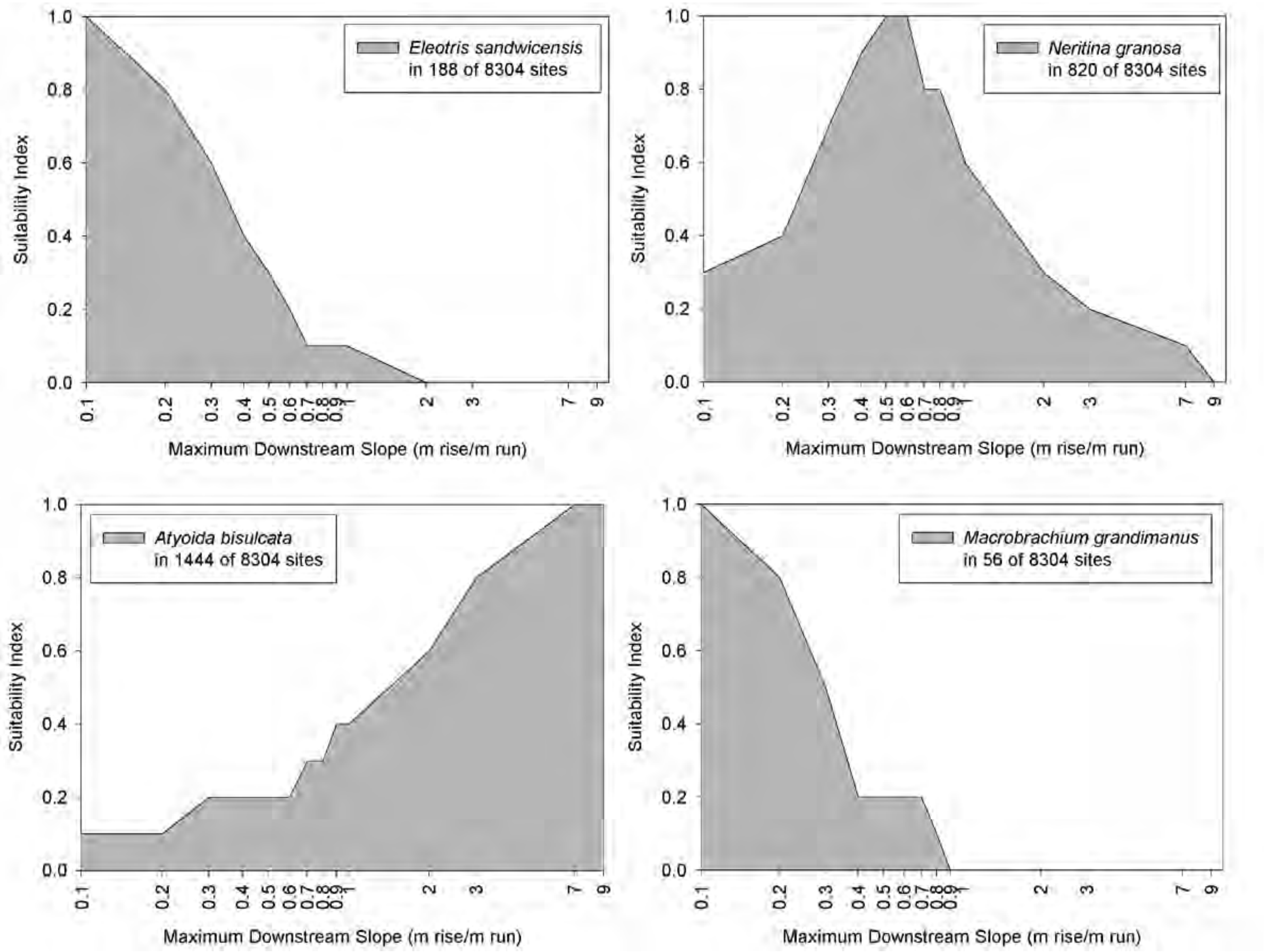


Figure 47. Suitability Indices for Barriers (maximum downstream slope over 10m distance) for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

Stream Reach Models:

Unlike in the watershed models, the variables used in the stream reach models were not linear; therefore, multiple logistic regressions could not be used to select the relationship between the instream distribution of the animals and the reach variables. To determine the suitability index based on the instream distribution for each species, the variables for elevation, distance inland, and downstream barrier height were combined with two different relationships and then the more appropriate relationship was selected for use. The two relationships were:

1. Reach Suitability = (Elevation Suitability + Distance Inland Suitability + Downstream Barrier Height Suitability)

where: if Elevation Suitability or Distance Inland Suitability or Downstream Barrier Height Suitability = 0, then Reach Suitability = 0

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Each relationship was range standardized with a minimum value of 0 and a maximum value of 1. To select the more appropriate relationship, the results of each relationship for all sites with all data for each variable in the database were calculated. The sites were grouped with the predicted results into bins from 0 to 1 by tenths and the proportion of samples with the species of concern was determined for each group. In cases where too few samples occurred in a bin (usually fewer than 100 of the 8300 samples in a single bin), the results were averaged with the nearest bin containing the fewest samples. The results of the comparison of predicted suitability with the proportion of samples containing a species were plotted on a graph and analyzed using linear regression.

To select the more appropriate relationship, two criteria were used. First, the distribution of predicted results to observed proportions was visually compared. If predicted values between 0 and 1 resulted in a range of proportions between 0 and 1, the relationship was considered acceptable. If both relationships were acceptable to the first criteria, then the relationship with the higher $r^2$ value for the linear regression was chosen.

The selected relationship to predict instream distribution of native stream animals were as follows:

*Awaous guamensis*:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher $r^2$ was selected.

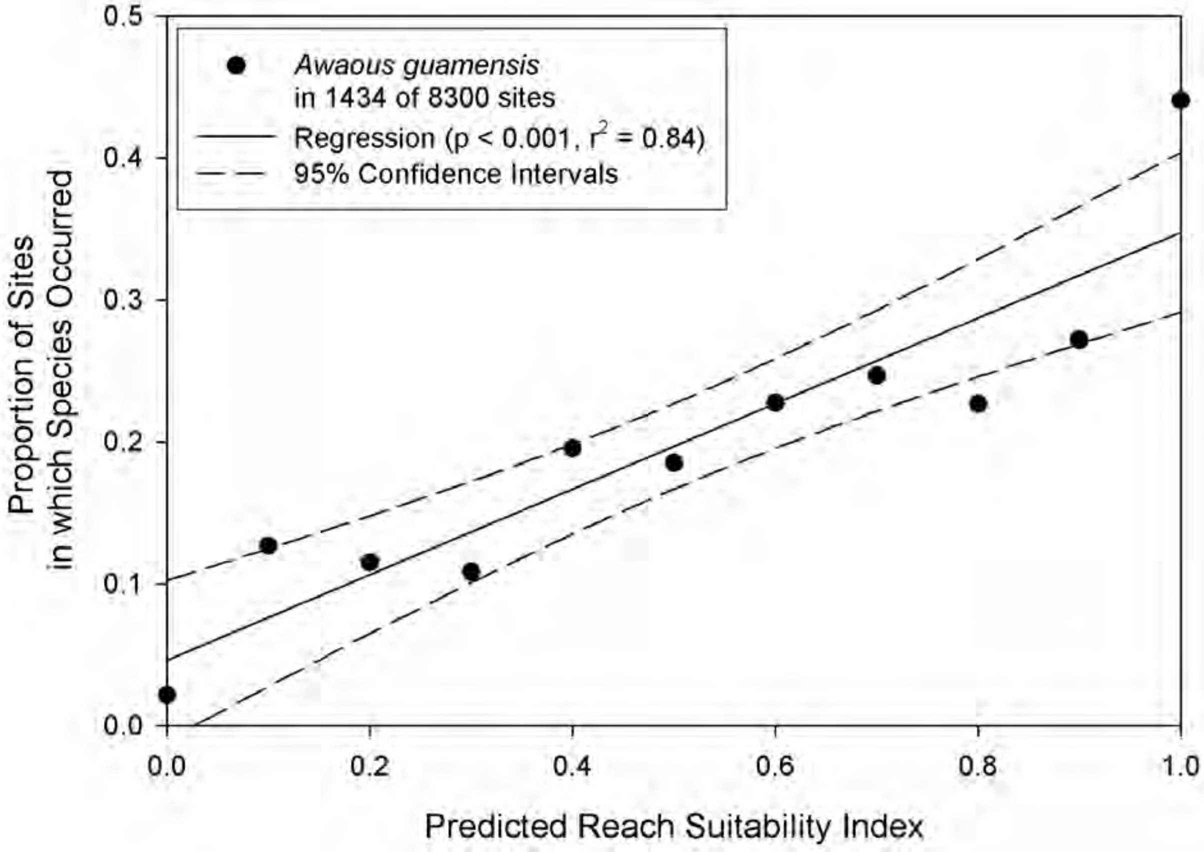


Figure 48. Proportion of the total sites where *Awaous guamensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Awaous guamensis*.

*Lentipes concolor*:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher $r^2$ was selected.

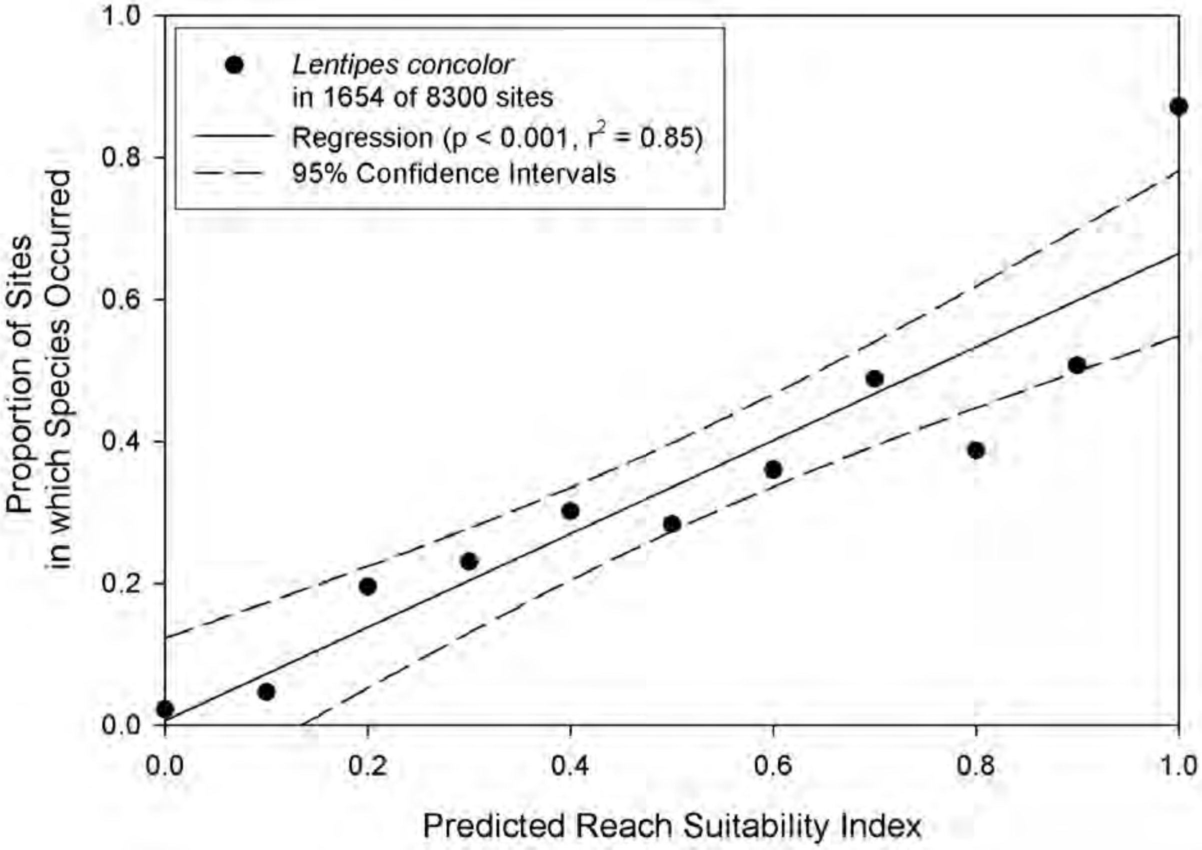


Figure 49. Proportion of the total sites where *Lentipes concolor* was observed within each 0.1 group of the Reach Suitability Index equation for *Lentipes concolor*.

*Sicyopterus stimpsoni*:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher $r^2$ was selected.

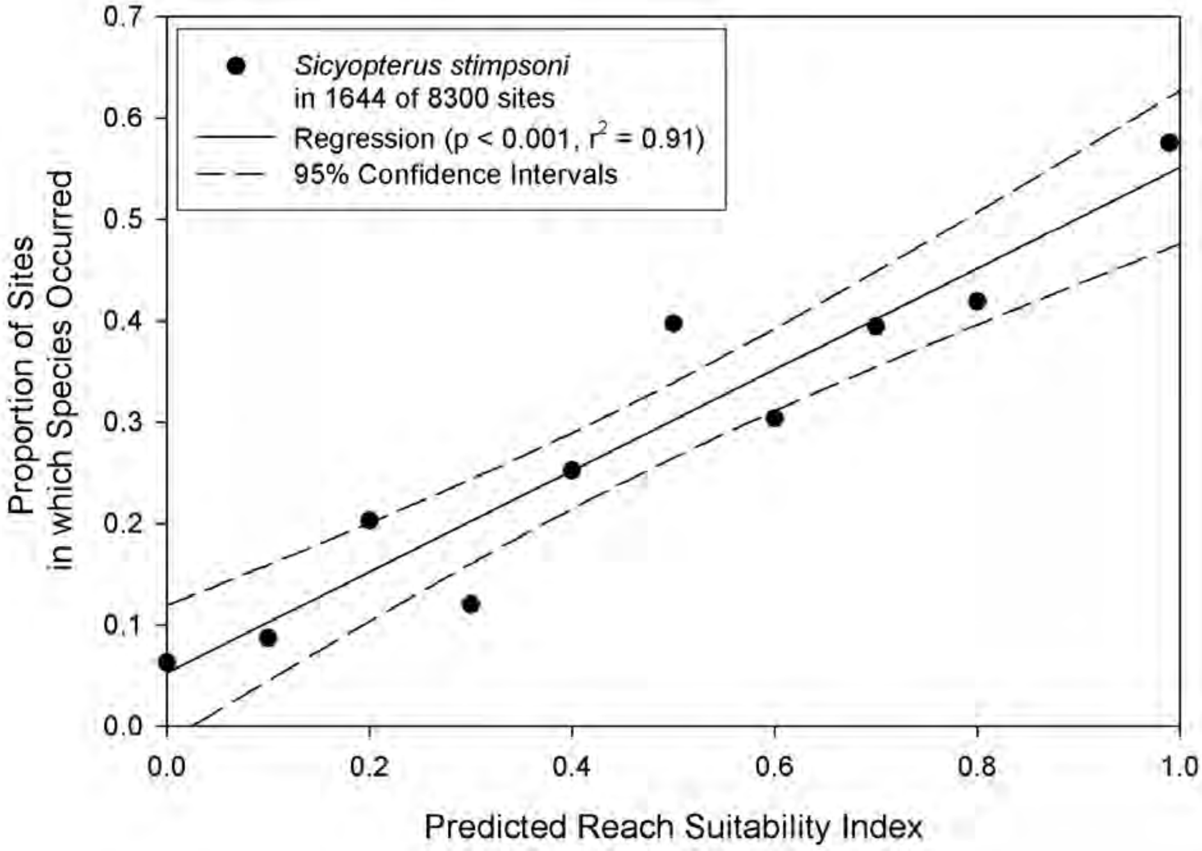


Figure 50. Proportion of the total sites where *Sicyopterus stimpsoni* was observed within each 0.1 group of the Reach Suitability Index equation for *Sicyopterus stimpsoni*.

*Stenogobius hawaiiensis*:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher $r^2$ was selected.

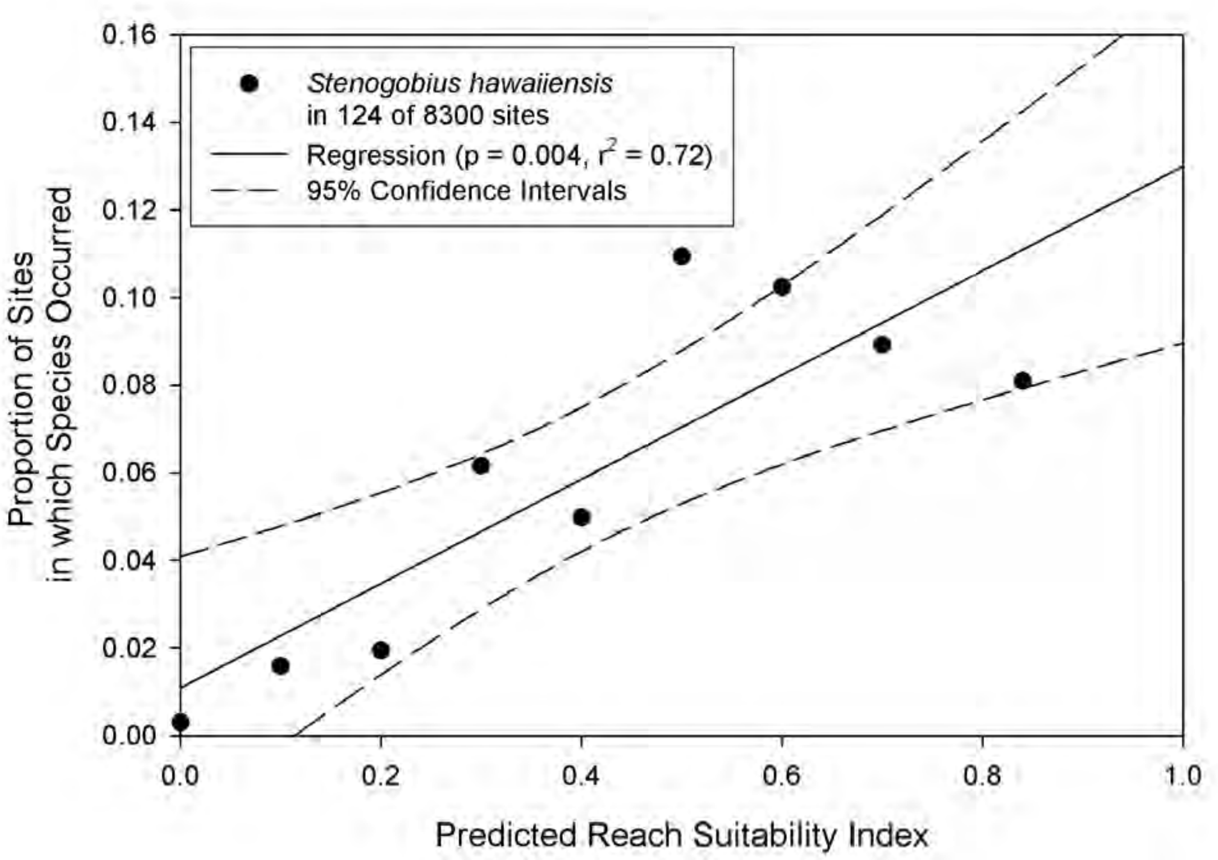


Figure 51. Proportion of the total sites where *Stenogobius hawaiiensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Stenogobius hawaiiensis*.

*Eleotris sandwicensis*:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher $r^2$ was selected.

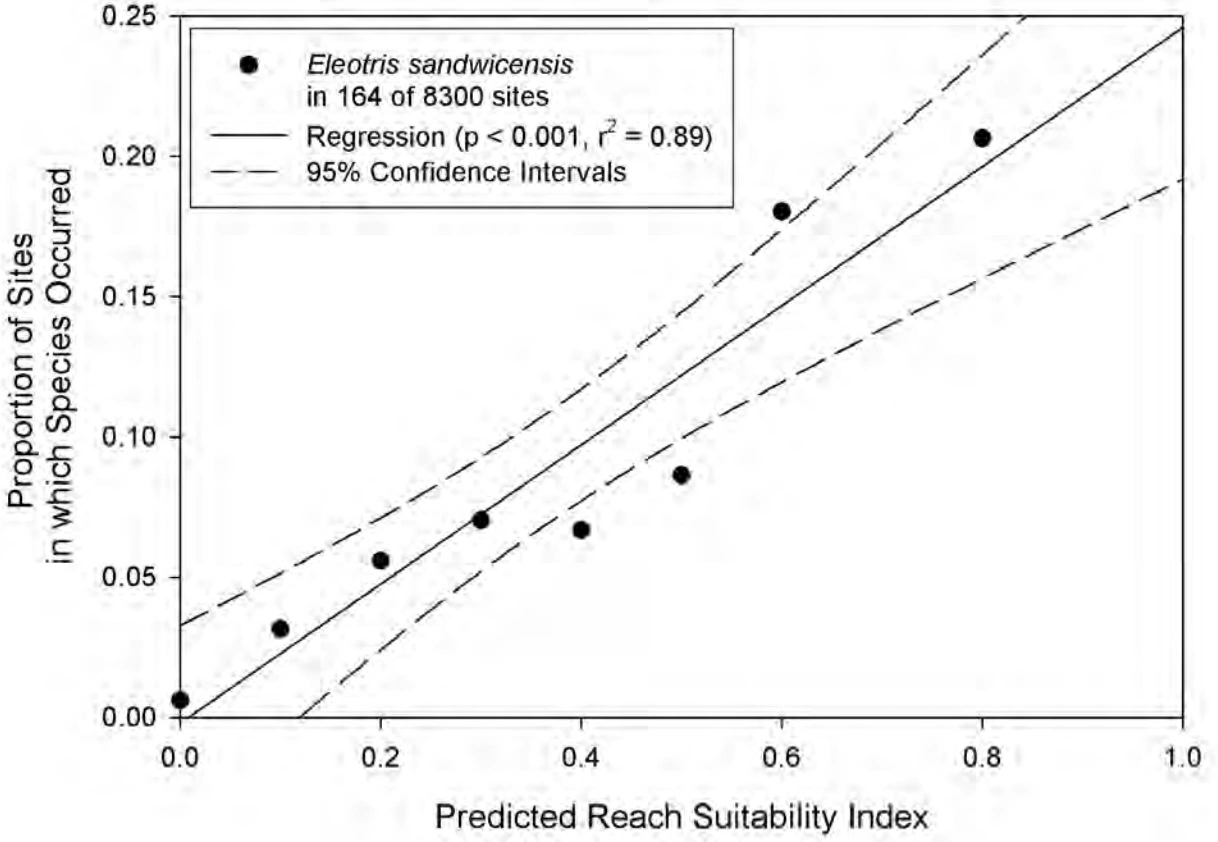


Figure 52. Proportion of the total sites where *Eleotris sandwicensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Eleotris sandwicensis*.

*Neritina granosa*:

The most appropriate relationship was:

2. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability).

Both relationships had adequate distributions and the equation with the higher $r^2$ was selected.

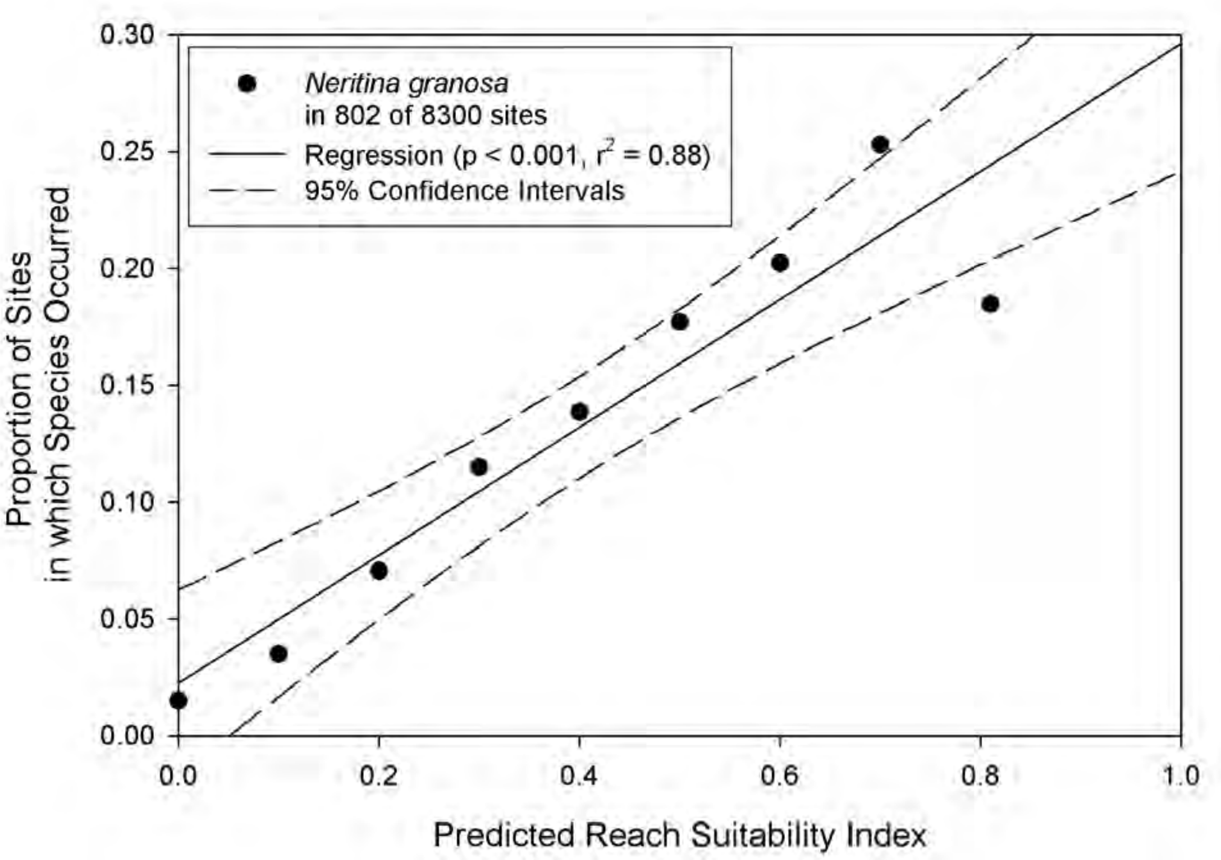


Figure 53. Proportion of the total sites where *Neritina granosa* was observed within each 0.1 group of the Reach Suitability Index equation for *Neritina granosa*.

*Atyoida bisulcata*:

The most appropriate relationship was:

1. Reach Suitability = (Elevation Suitability * Distance Inland Suitability * Downstream Barrier Height Suitability)

Both relationships had adequate distributions and the equation with the higher $r^2$ was selected.

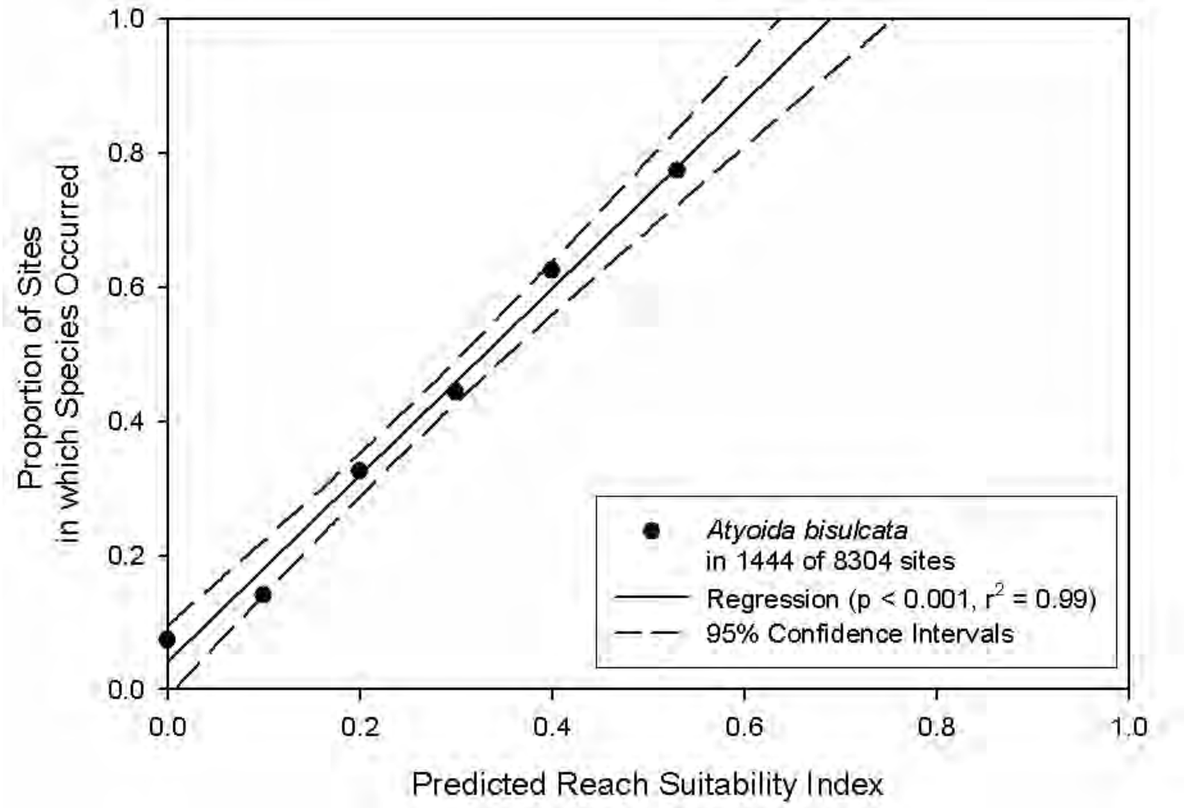


Figure 54. Proportion of the total sites where *Atyoida bisulcata* was observed within each 0.1 group of the Reach Suitability Index equation for *Atyoida bisulcata*.

*Macrobrachium grandimanus*:

The most appropriate relationship was:

1. Reach Suitability = (Elevation Suitability + Distance Inland Suitability + Downstream Barrier Height Suitability)

where: if Elevation Suitability or Distance Inland Suitability or Downstream Barrier Height Suitability = 0, then Reach Suitability = 0

Both relationships had adequate distributions and the equation with the higher $r^2$ was selected.

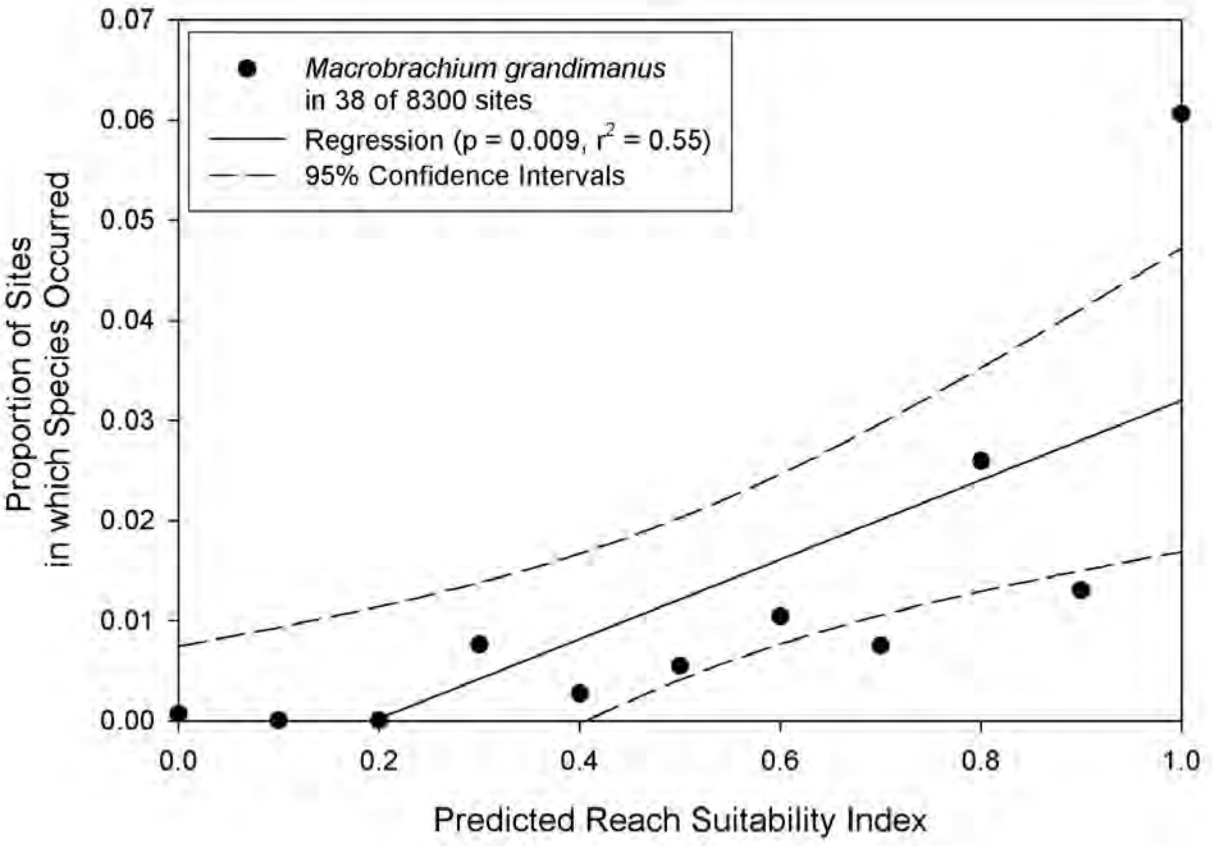


Figure 55. Proportion of the total sites where *Macrobrachium grandimanus* was observed within each 0.1 group of the Reach Suitability Index equation for *Macrobrachium grandimanus*.

Site level habitat availability:

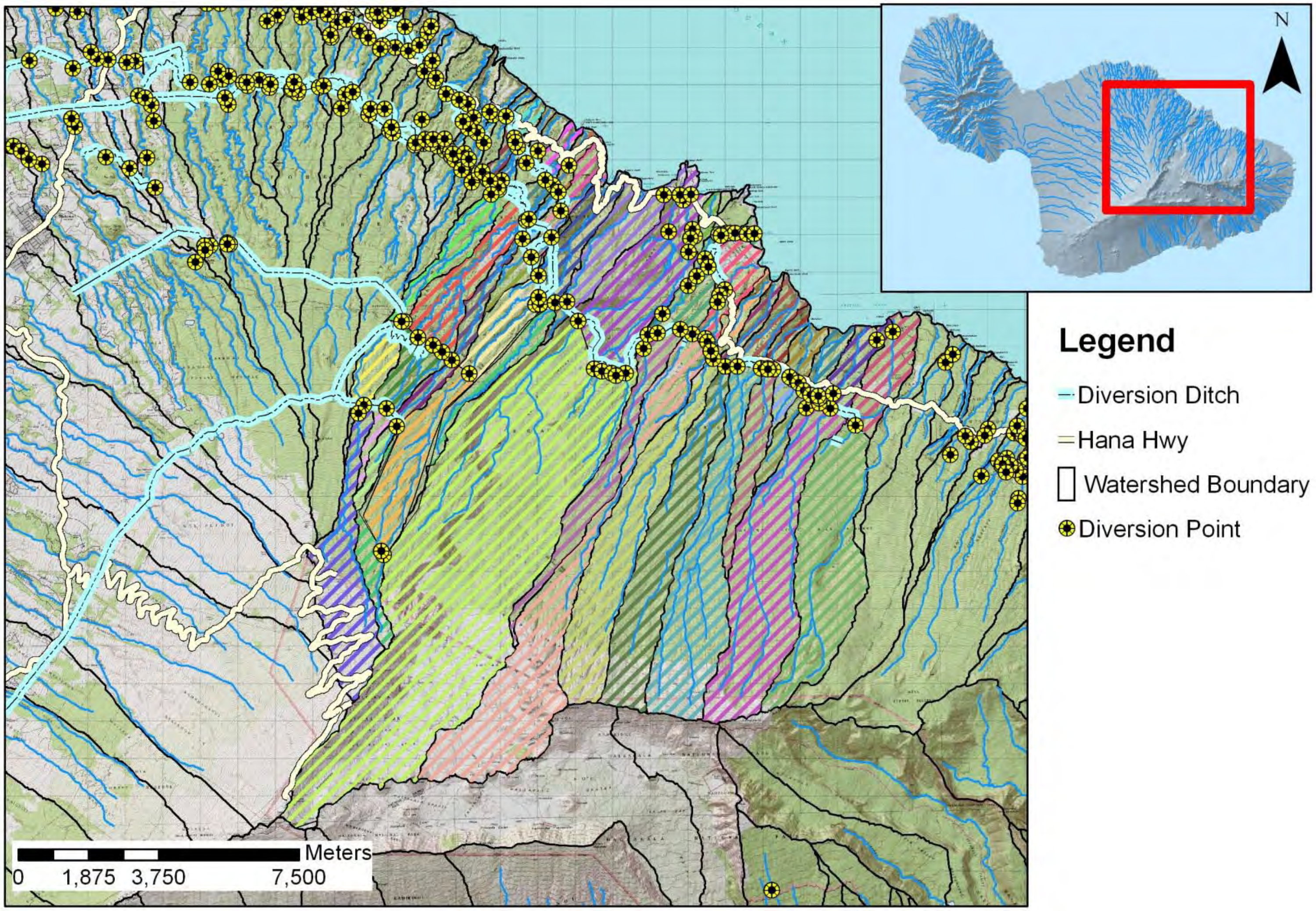


Figure 56. Zones related to the diversion systems on East Maui streams. Zones are the portion of a watershed upstream, between, or downstream of a diversion.

Table 3. Watershed Zones related to location of stream diversions. Zones are numbered in a downstream direction with Zone 1 upstream of all diversions and Zone 5 downstream of all diversion. Zones 2, 3, and 4 are in between diversions. Diversions are noted by D1 to 4. Not all watersheds have all five zones. Additional information includes the stream length with each zone, the percent habitat available for all species except *Atyoida bisulcata* and the percent habitat available for *Atyoida bisulcata*. Percent habitat available is based on Gingerich and Wolff, 2005. The upstream and downstream migration percentages reflect an 80% loss of migration time due to complete dewatering of streams at diversion site during low to moderate flows. Multiple diversions lose an additional 80% of remaining animals at each crossing. In large dewatered stream sections a 50% loss is predicted.

| Stream Name Location in Watershed | Location in Watershed With respect To diversions | Watershed Zone ID | Stream Length (m) | General Species % Habitat Available | Atyoida % Habitat Available | Upstream Migration % | Downstream Migration % |
|---|---|---|---|---|---|---|---|
| Kōlea | Upstream D4 | 640034 | 1,750 | 100 | 100 | 20 | 20 |
| Kōlea | Downstream D4 | 640035 | 1,920 | 61 | 72 | 100 | 100 |
| Waikamoi | Upstream D1 | 640041 | 9,950 | 100 | 100 | 0 | 0 |
| Waikamoi | Between D1 – D2 | 640042 | 3,750 | 61 | 72 | 1 | 1 |
| Waikamoi | Between D2 – D3 | 640043 | 11,630 | 61 | 72 | 2 | 2 |
| Waikamoi | Between D3 – D4 | 640044 | 3,250 | 57 | 70 | 10 | 10 |
| Waikamoi | Downstream D4 | 640045 | 1,710 | 18 | 26 | 50 | 50 |
| Puohokamoa | Upstream D1 | 640061 | 380 | 100 | 100 | 0 | 0 |
| Puohokamoa | Between D1 – D2 | 640062 | 7,300 | 61 | 72 | 1 | 1 |
| Puohokamoa | Between D2 – D3 | 640063 | 15,550 | 58 | 70 | 4 | 4 |
| Puohokamoa | Between D3 – D4 | 640064 | 1,610 | 43 | 60 | 20 | 20 |
| Puohokamoa | Downstream D4 | 640065 | 2,600 | 53 | 67 | 100 | 100 |
| Haipuaʻena | Upstream D1 | 640071 | 1,530 | 100 | 100 | 0 | 0 |
| Haipuaʻena | Between D1 – D2 | 640072 | 3,330 | 61 | 72 | 1 | 1 |
| Haipuaʻena | Between D2 – D3 | 640073 | 5,980 | 53 | 67 | 4 | 4 |
| Haipuaʻena | Between D3 – D4 | 640074 | 2,310 | 42 | 59 | 20 | 20 |
| Haipuaʻena | Downstream D4 | 640075 | 2,640 | 54 | 68 | 100 | 100 |
| Punalau | Upstream D3 | 640083 | 1,940 | 100 | 100 | 4 | 4 |
| Punalau | Between D3 – D4 | 640084 | 2,130 | 100 | 100 | 20 | 20 |
| Punalau | Downstream D4 | 640085 | 2,060 | 46 | 62 | 100 | 100 |
| Honomanū | Upstream D1 | 640091 | 10,750 | 100 | 100 | 1 | 1 |
| Honomanū | Between D1 – D2 | 640092 | 11,980 | 61 | 72 | 2 | 2 |
| Honomanū | Between D2 – D3 | 640093 | 7,670 | 86 | 90 | 10 | 10 |
| Honomanū | Downstream D3 | 640095 | 7,360 | 0 | 0 | 50 | 50 |
| Nuaʻailua | Upstream D1 | 640101 | 1,460 | 100 | 100 | 20 | 20 |
| Nuaʻailua | Downstream D1 | 640105 | 5,280 | 100 | 100 | 100 | 100 |
| ʻŌhiʻa | Downstream D1 | 640125 | 1,170 | 100 | 100 | 100 | 100 |
| W. Wailua Iki | Upstream D1 | 640151 | 15,410 | 100 | 100 | 20 | 20 |
| W. Wailua Iki | Downstream D1 | 640155 | 3,650 | 47 | 63 | 100 | 100 |

Table 3. continued.

| Stream Name Location in Watershed | Location in Watershed With respect To diversions | Watershed Zone ID | Stream Length (m) | General Species % Habitat Available | Atyoida % Habitat Available | Upstream Migration % | Downstream Migration % |
|---|---|---|---|---|---|---|---|
| E. Wailua Iki | Upstream D1 | 640161 | 15,840 | 100 | 100 | 20 | 20 |
| E. Wailua Iki | Downstream D1 | 640165 | 3,630 | 52 | 66 | 100 | 100 |
| Kopiliʻula | Upstream D1 | 640171 | 25,440 | 100 | 100 | 20 | 20 |
| Kopiliʻula | Downstream D1 | 640175 | 5,940 | 67 | 72 | 100 | 100 |
| Waiohue | Upstream D1 | 640181 | 2,970 | 100 | 100 | 20 | 20 |
| Waiohue | Downstream D1 | 640185 | 2,330 | 57 | 69 | 100 | 100 |
| Paakea Gulch | Upstream D1 | 640191 | 1,690 | 100 | 100 | 20 | 20 |
| Paakea Gulch | Downstream D1 | 640195 | 2,730 | 97 | 98 | 100 | 100 |
| Kapāʻula Gulch | Upstream D1 | 640211 | 3,000 | 100 | 100 | 20 | 20 |
| Kapāʻula Gulch | Downstream D1 | 640215 | 2,540 | 76 | 83 | 100 | 100 |
| Hanawī | Upstream D1 | 640221 | 25,120 | 100 | 100 | 20 | 20 |
| Hanawī | Downstream D1 | 640225 | 3,320 | 61 | 72 | 100 | 100 |
| Makapipi | Upstream D1 | 640231 | 13,250 | 100 | 100 | 20 | 20 |
| Makapipi | Downstream D1 | 640235 | 4,170 | 61 | 72 | 100 | 100 |

Results and Discussion:

The results and discussion portions of this report are combined for the 16 different streams and their tributaries and 8 species. DAR Biologists surveyed many of the streams to determine current conditions to aid in the instream flow determinations by CWRM. The information gathered from these surveys was not used to develop the model, so they could be used to compare the predictions with the observed conditions. While some streams were surveyed more extensively than others due to time, access, and weather conditions, DAR provided a standardized report on the finding for each stream. Each stream report will be cited in a similar manner to improve understanding of which report is being referred. The general citation is as follows:

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamoʻo, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. **Report on Kōlea Stream, Maui, Hawai‘i**. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 36 p.

All reports follow a similar citation with the only change being the name of the stream and total pages. In this report, the in text citation for these reports are (Report on Kōlea Stream, 2009) instead of the standard (Higashi et al., 2009a through r) for reader ease, as understanding the stream associated with the arbitrary a through r designation would be difficult. Additionally, the new reports for each stream contain updated pages for the associated information contained in the *Atlas of Hawaiian Watersheds & Their Aquatic Resources* (Parham et al., 2008), as well as a report on any point quadrat surveys completed, and any estuary surveys completed. These report sections are not separately referenced.

In the following stream by stream discussions, each stream will refer to a map of the habitat suitability for each species on the stream of concern and a table with the changes in the amount of available habitat as a result of stream diversion and entrainment of migrating individuals.

Maps for the area cover the following species:

Figure 57. Predicted Habitat Suitability Index (HSI) for *Awaous guamensis.*
Figure 58. Predicted Habitat Suitability Index (HSI) for *Lentipes concolor.*
Figure 59. Predicted Habitat Suitability Index (HSI) for *Sicyopterus stimpsoni.*
Figure 60. Predicted Habitat Suitability Index (HSI) for *Stenogobius hawaiiensis.*
Figure 61. Predicted Habitat Suitability Index (HSI) for *Eleotris sandwicensis.*
Figure 62. Predicted Habitat Suitability Index (HSI) for *Neritina granosa.*
Figure 63. Predicted Habitat Suitability Index (HSI) for *Atyoida bisulcata.*
Figure 64. Predicted Habitat Suitability Index (HSI) for *Macrobrachium grandimanus.*

The maps are colorized with green colors which reflect high values for habitat suitability and red colors which reflect low values for habitat suitability. It is important to understand that these scales are based on the comparison with the most suitable habitats in the state. For some species, the most suitable habitat may not occur on Maui and thus the maximum intensity of green colors (maximum value for suitable habitat) does not necessarily occur in East Maui. Therefore, habitat suitability is scaled from 0 to 1 among all streams in the state, not just the East Maui streams.

Tables for the area cover the following species:

Table 4. Summary of the amount of habitat units for *Awaous guamensis.*
Table 5. Summary of the amount of habitat units for *Lentipes concolor.*
Table 6. Summary of the amount of habitat units for *Stenogobius hawaiiensis.*
Table 7. Summary of the amount of habitat units for *Sicyopterus stimpsoni.*
Table 8. Summary of the amount of habitat units for *Eleotris sandwicensis.*
Table 9. Summary of the amount of habitat units for *Neritina granosa.*
Table 10. Summary of the amount of habitat units for *Atyoida bisulcata.*
Table 11. Summary of the amount of habitat units for *Macrobrachium grandimanus.*
Table 12. Summary of the combined total amount of habitat units for all native species.

A second important issue is related to understanding the meaning of the amount of habitat in the tables. Although the table gives the amount of suitable habitat in meters, it does not necessarily mean that the habitat is all continuous or that there are only X meters of highly suitable habitat. The measure of the amount of suitable habitat is a combination of the linear distance of the habitat type and the suitability of that habitat type. For example, 10 segments of 10 m each may have low suitability (value of 0.2) for a species. This would result in 20 m of suitable habitat (100 m * 0.2 suitability). It would be a low probability that a species would be in any particular location, but a few individuals may be found in the 100m segment. Contrast this to 2 segments of 10 m each with high suitability (value of 1.0). Here the resulting 20 m of suitable habitat (20 m * 1.0 suitability) would have a high probability of containing the species. When viewing the result of the amount of habitat it is important to remember that the table provides a summary of the amount of suitable habitat in the stream and does not show the distribution of the suitable habitat.

The following is a stream by stream discussion of the HSHEP model results.

### Kōlea Stream:

Kōlea Stream is small and steep with a terminal waterfall (Report on Kōlea Stream, 2009). As a result there was little suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Lentipes concolor* (1,136 m) followed by *Neritina granosa* (348 m), *Awaous guamensis* (295 m), *Sicyopterus stimpsoni* (190 m), and *Atyoida bisulcata* (140 m). In general, 50 to 80% of the habitat for these species was predicted to be lost with about 20% of that loss due to flow diversion and the rest due to entrainment issues. Few surveys were completed in this stream and none of these animals were observed (Report on Kōlea Stream, 2009). It was noted that low flow conditions provided little habitat in the areas surveyed.

From a ranking perspective, Kōlea Stream did not rank highly for the amount of potential suitable habitat for any species in comparison with the other stream in this analysis with only one stream, ʻŌhiʻa Stream, having less total habitat units in the stream predicted prior to diversion.

This fits with the description of the stream as small and steep with a terminal waterfall. Overall, the results of the HSHEP model predicted approximately 2.1 km of habitat for all species combined in Kōlea Stream with 65.7% of this lost due to the combined low flow and entrainment effects of the stream diversion. *Lentipes concolor* was expected to be the most common native species. Restoration of flow, especially related to providing passage for stream animals, and protection from entrainment would likely result in increased habitat availability for native species. The presence of a reservoir in this stream likely complicates fish passage issues. Currently it is unknown if the reservoir inhibits upstream or downstream migration success.

### Waikamoi Stream:

Waikamoi Stream is narrow and steep with a terminal waterfall (Report on Waikamoi Stream, 2009). As a result there was little suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Lentipes concolor* (3,558 m) followed by *Atyoida bisulcata* (2,193 m), *Neritina granosa* (579 m), *Awaous guamensis* (462 m), and *Sicyopterus stimpsoni* (288 m). In general, almost all habitats for native species (97 to 99%) were predicted to be lost with about 30% to 60% of that loss due to flow diversion and the rest due to entrainment issues. The surveys conducted by DAR support the modeled predictions. *Lentipes concolor* and *Atyoida bisulcata* were observed in a few stream pools. Dry sections of the stream bed were observed below the diversion and where surveyed the diversion removed 100% of the stream flow. It was noted that low flow conditions provided little habitat in the areas downstream of the diversions (Report on Waikamoi Stream, 2009). Entrainment of downstream drifting larvae would be high in this stream and upstream passage would be limited to high flow events.

From a ranking perspective, Waikamoi Stream ranked in the top 5 streams for the amount of potential suitable habitat for *Lentipes concolor*, *Atyoida bisulcata*, and *Awaous guamensis* in comparison with the other stream in this analysis. Overall, the results of the HSHEP model predicted approximately 7 km of habitat for all species combined in Waikamoi Stream with 99.0% of this lost due to the combined effects of the stream diversion. Restoration of flow to increase local habitat and improve fish passage would benefit the stream greatly by providing large amounts of habitat for native species. Flow restoration and improvements to fish passage should proceed in an upstream direction from the stream mouth.

### Puohokamoa Stream:

Puohokamoa Stream is steep in the middle reach with a bedrock and boulder channel (Report on Puohokamoa Stream, 2009). There was a very small amount of suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Lentipes concolor* (5,094 m) followed by *Atyoida bisulcata* (3,450 m), *Neritina granosa* (1,239 m), *Awaous guamensis* (1,190 m), and *Sicyopterus stimpsoni* (821 m). In general, the amount of remaining suitable habitat for native species decreased in an upstream direction. This resulted in the most habitat units lost for *Atyoida bisulcata* and then *Lentipes concolor*. The surveys conducted by DAR and USGS support the modeled predictions. Most native species expected were observed in Puohokamoa Stream by DAR or USGS surveys, although most present in low numbers and were restricted to stream pools. Dry sections of the stream bed were observed below the diversion and where surveyed the diversion removed 100% of the stream flow. It was noted that low flow conditions provided little habitat in the areas downstream of the diversions (Report on Puohokamoa Stream, 2009). Entrainment of downstream drifting larvae would be high in this stream and upstream passage would be limited to high flow events.

From a ranking perspective, Puohokamoa Stream ranked as the top stream for the amount of suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 11.9 km of habitat for all species combined in Puohokamoa Stream with 81.5% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 9.7 km of habitat units in this stream alone and it ranked second among all streams in this report. Restoration of flow to increase local habitat and improve fish passage would benefit the stream greatly by providing large amounts of habitat for native species. Flow restoration and improvements to fish passage should proceed in an upstream direction from the stream mouth.

### Haipuaʻena Stream:

Haipuaʻena Stream is a small and steep stream (Report on Haipuaʻena Stream, 2009). There was little suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Atyoida bisulcata* (3,755 m) followed by *Lentipes concolor* (1,682 m), *Neritina granosa* (288 m), *Awaous guamensis* (124 m), and *Sicyopterus stimpsoni* (117 m). In general, the amount of remaining suitable habitat for native species decreased in an upstream direction. This resulted in the most habitat units lost for *Atyoida bisulcata* and then *Lentipes concolor*. No recent surveys were conducted in this stream, although historical survey data suggest habitat was present for *Atyoida bisulcata* and *Lentipes concolor* as well as aquatic insects (Report on Haipuaʻena Stream, 2009). In general, 55 to 90% of the habitat for these species was predicted to be lost with about 40% of that loss due to flow diversion and the rest due to entrainment issues. Entrainment of downstream drifting larvae would be high in this stream and upstream passage would be limited to high flow events.

From a ranking perspective, Haipuaʻena Stream had about average amounts of suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 5.9 km of habitat for all species combined in Haipuaʻena Stream with 86.7% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 5.1 km of habitat units in this stream and it ranked fourth among all streams in this report. Restoration of flow to increase local habitat and improve fish passage would benefit the stream by increasing habitat for native species.

### Punalau Stream:

Punalau Stream is a small and steep stream that enters Honomanū Bay (Report on Punalau Stream, 2009). Small amounts of suitable habitat were predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Lentipes concolor*

(2,257 m) followed by *Atyoida bisulcata* (777 m), *Awaous guamensis* (604 m), *Neritina granosa* (458 m), and *Sicyopterus stimpsoni* (370 m). In general, the amount of remaining suitable habitat for native species decreased in an upstream direction. This resulted in the most habitat units lost for *Lentipes concolor* and then *Atyoida bisulcata*. Surveys conducted by DAR in Punalau Stream suggest that flow diversions have decreased habitat availability and fish passage in the middle reach of this stream (Report on Punalau Stream, 2009). In general, 60 to 95% of the habitat for these species were predicted to be lost with a range of 2.5% for *Atyoida bisulcata* to 43.9% for *Sicyopterus stimpsoni* of that loss due to flow diversion and the rest due to entrainment issues. Entrainment of downstream drifting larvae would be high in this stream and upstream passage would be limited to high flow events for the upstream species.

From a ranking perspective, Punalau Stream had less than average amounts of suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 4.6 km of habitat for all species combined in Punalau Stream with 76.7% of this lost due to the combined effects of the stream diversion. There is the potential to recover almost 3.5 km of habitat units in this stream and it ranked ninth among all streams in this report for its restoration potential. Restoration of flow to increase local habitat and improve fish passage would benefit the stream by increasing habitat for native species.

### Honomanū Stream:

Honomanū Stream has one of the larger estuaries and low reaches of any stream covered in this report. It has a steep middle and upper reach typical of many East Maui Streams (Report on Honomanū Stream, 2009). Honomanū Stream has the largest amount of suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis* (153 m), *Eleotris sandwicensis* (192 m), and *Macrobrachium grandimanus* (447 m). Both *Eleotris sandwicensis* and *Macrobrachium grandimanus* were observed during stream surveys, although there numbers were very low and their distribution limited (Report on Honomanū Stream, 2009). For the climbing species, the most habitat was predicted for *Atyoida bisulcata* (5,041 m) followed by *Lentipes concolor* (3,844 m), *Awaous guamensis* (1,689 m), *Sicyopterus stimpsoni* (1,199 m), and *Neritina granosa* (950 m). In general, almost all suitable habitat (99.7%) were predicted to be lost in Honomanū Stream as a result of stream diversions. The surveys conducted by DAR support the modeled predictions. A few native species were observed in Honomanū Stream during surveys, although most were present in low numbers and were restricted to the few available stream pools. Dry sections of the stream bed were observed below the diversion and where surveyed, the diversion removed 100% of the stream flow. It was noted that low flow conditions provided little habitat in the areas downstream of the diversions (Report on Honomanū Stream, 2009). Entrainment of downstream drifting larvae would be high in this stream and upstream passage would be limited to high flow events.

From a ranking perspective, Honomanū Stream ranked as the second stream for the amount of potential suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 13.5 km of habitat for all species combined in Honomanū Stream with 99.8% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 13.4 km of habitat units in this stream and it ranked first among all streams in this report for its potential for restoration. Restoration of flow to increase local habitat and improve fish passage would benefit the stream greatly by providing large amounts of habitat for native species.

### Nuaʻailua Stream:

Nuaʻailua Stream is a small and steep stream with a small estuary (Report on Nuaʻailua Stream, 2009). There was some suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. In surveys in the lower reach *Eleotris sandwicensis* were observed. For the climbing species, the most habitat was predicted for *Lentipes concolor* (1,711 m) followed by *Awaous guamensis* (1706 m), *Neritina granosa* (801 m), *Sicyopterus stimpsoni* (879 m), and *Atyoida bisulcata* (646 m). In general, most habitats were predicted to still occur in the stream. Recent surveys showed a range of native species and generally good habitat conditions, which was consistent with the HSHEP modeled estimates (Report on Nuaʻailua Stream, 2009). In general, some entrainment of downstream drifting larvae may occur in this stream and upstream passage may be limited during dry periods.

From a ranking perspective, Nuaʻailua Stream had little less than average amounts of suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 5.3 km of habitat for all species combined in Nuaʻailua Stream with 9.8% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 0.5 km of habitat units in this stream alone and it ranked fifteenth among all streams in this report. Restoration of flow to improve fish passage would have limited benefits to the stream by decreasing entrainment of drifting larvae for native species.

### ʻŌhiʻa Stream:

ʻŌhiʻa Stream is a small spring fed stream (Report on ʻŌhiʻa Stream, 2009). There was little suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Sicyopterus stimpsoni* (231 m) followed by *Awaous guamensis* (228 m), *Neritina granosa* (137 m), and *Lentipes concolor* (78 m). The stream was not expected to have any loss of habitat as no diversions were located on this stream. Recent surveys observed *Lentipes concolor*, *Atyoida bisulcata*, and *Neritina granosa* and generally good habitat conditions (Report on ʻŌhiʻa Stream, 2009). In general, stream conditions in ʻŌhiʻa were good and most problems were associated with hau, *Hibiscus tiliaceus*, growing in the stream.

From a ranking perspective, ʻŌhiʻa Stream had smallest amounts of suitable habitat for native species in comparison with the other stream in this analysis. Overall, the results of the HSHEP model predicted less than 1 km of habitat for all species combined in ʻŌhiʻa Stream with 0% of this lost due to the combined effects of the stream diversion. There is no need to attempt restoration associated with stream diversion as no diversion currently exist. Removal of hau, *Hibiscus tiliaceus*, growing in the stream may improve fish passage for native species.

## West Wailua Iki Stream:

West Wailua Iki watershed is a narrow and steep with a small estuary (Report on West Wailua Iki Stream, 2009). There were small amounts of suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis, Eleotris sandwicensis,* and *Macrobrachium grandimanus*. In surveys in the lower reach *Eleotris sandwicensis* were observed. For the climbing species, the most habitat was predicted for *Lentipes concolor* (2,255 m) followed by *Atyoida bisulcata* (2,000 m), *Awaous guamensis* (500 m), *Neritina granosa* (425 m), and *Sicyopterus stimpsoni* (423 m). In general, flow diversion eliminated about 50% of the habitat for the middle reach species (*Awaous guamensis*, *Sicyopterus stimpsoni,* and *Neritina granosa*) and entrainment issues associated with the diversion had a large influence on *Lentipes concolor* and *Atyoida bisulcata*. Recent surveys found a range of native species in the stream although substantial loss of habitat was reported below the diversions (Report on West Wailua Iki Stream, 2009).

From a ranking perspective, West Wailua Iki Stream had about average amounts of suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 5.7 km of habitat for all species combined in West Wailua Iki Stream with 70.5% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 4 km of habitat units in this stream and it ranked seventh among all streams in this report. Restoration of flow to increase local habitat and improve fish passage would benefit the stream by increasing habitat for native species.

## East Wailua Iki Stream:

East Wailua Iki Stream is a steep stream with stair step waterfalls and plunge pools above Hana Highway (Report on East Wailua Iki Stream, 2009). There was some suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus* and *Eleotris sandwicensis* were observed in the surveys. For the climbing species, the most habitat was predicted for *Lentipes concolor* (2,589 m) followed by *Atyoida bisulcata* (1,477 m), *Sicyopterus stimpsoni* (813 m), *Neritina granosa* (787 m), and *Awaous guamensis* (717 m). In general, the loss of instream habitat was due to water removal which resulted in about 45% loss of habitat for lower and middle reach species, while *Lentipes concolor* and *Atyoida bisulcata* were mostly affected by entrainment issues. Recent surveys found a range of native species, but noted that much habitat was lost due to flow diversion (Report on East Wailua Iki Stream, 2009).

From a ranking perspective, East Wailua Iki Stream had above average amounts of potential suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 6.5 km of habitat for all species combined in East Wailua Iki Stream with 67% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 4.3 km of habitat units in this stream and it ranked sixth among all streams in this report. Restoration of flow to increase local habitat and improve fish passage would improve stream conditions for native species.

**Kopiliʻula Stream:**

Kopiliʻula Stream is a narrow and steep watershed with a small embayment (Report on Kopiliʻula Stream, 2009). Kopiliʻula Stream has a tributary called Puaʻakaʻa connecting to the main stem of Kopiliʻula Stream. There was some suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis,* and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Lentipes concolor* (3,871 m) followed by *Atyoida bisulcata* (2,078 m), *Neritina granosa* (1,115 m), *Sicyopterus stimpsoni* (1,021 m), and *Awaous guamensis* (1,004 m). All of the climbing species were observed in the stream surveys and noted generally good habitat conditions (Report on Kopiliʻula Stream, 2009). In general, the loss of instream habitats due to water removal resulted in about 20 to 45% loss of habitat for these species, and *Lentipes concolor* and *Atyoida bisulcata* were mostly affected by entrainment issues.

From a ranking perspective, Kopiliʻula Stream had large amounts of potential suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 9.2 km of habitat for all species combined in Kopiliʻula Stream with 55.5% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 5.1 km of habitat units in this stream and it ranked fifth among all streams in this report. Restoration of flow to increase local habitat and improve fish passage would improve stream conditions for native species.

**Waiohue Stream:**

Waiohue Stream is small, narrow, and steep with a small embayment (Report on Waiohue Stream, 2009). There were small amounts of suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Lentipes concolor* (1,895 m) followed by *Atyoida bisulcata* (718 m), *Neritina granosa* (621 m), *Awaous guamensis* (579 m), and *Sicyopterus stimpsoni* (521 m). All of the climbing species were observed in the stream surveys except *Lentipes concolor* and *Atyoida bisulcata* were found in high abundances above the diversion (Report on Waiohue Stream, 2009). In general, the loss of instream habitats due to water removal resulted in about 40% loss of instream habitat for these species, and *Lentipes concolor* and *Atyoida bisulcata* were affected more by entrainment issues than the other species. *Atyoida bisulcata* provides a good example of an animal that is using typical habitats, but must lose high proportions of their downstream drifting larvae to the diversion which take almost all of the water at normal discharge levels. The HSHEP model considers these animals to be located in low suitability habitat even though the adults are surviving just fine. The HSHEP model considers upstream movement, adult habitat, and downstream drift in determining if habitat is useful for the maintenance of the species.

From a ranking perspective, Waiohue Stream had less than average amounts of potential suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 4.4 km of habitat for all species combined in Waiohue Stream with 61.4% of this lost due to the combined effects of the stream diversion. There is the potential to recover almost 2.7 km of habitat units in this stream and it ranked eleventh among all streams in this report. Restoration of flow to increase local habitat and especially to improve fish passage would improve stream conditions for native species.

## Paakea Gulch:

Paʻakea Gulch is small, narrow, and steep with a small embayment (Report on Paʻakea Gulch, 2009). There were very small amounts of suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. *Eleotris sandwicensis* was observed in a plunge pool just inland from the ocean and at the base of a waterfall. (Report on Paʻakea Gulch, 2009). For the climbing species, the most habitat was predicted for *Lentipes concolor* (1,732 m) followed by *Neritina granosa* (831 m), *Awaous guamensis* (770 m), *Sicyopterus stimpsoni* (665 m), and *Atyoida bisulcata* (288 m). All of the climbing species were observed in the stream surveys (Report on Paʻakea Gulch, 2009). In general, the loss of instream habitats due to water removal resulted in about 3% loss of habitat for these species, as springs in the lower stream sections provide adequate stream flow for native animals in these sections of the stream. *Atyoida bisulcata* were more affected by entrainment issues than the other species as they were found upstream of the diversion.

From a ranking perspective, Paʻakea Gulch had less than average amounts of potential suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 4.4 km of habitat for all species combined in Paʻakea Gulch with 20.9% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 0.9 km of habitat units in this stream and it ranked fourteenth among all streams in this report. Restoration of flow to improve fish passage at upstream sites would improve stream conditions for native species.

## **Kapāʻula Gulch**:

Kapāʻula Gulch is small, narrow, and steep without an embayment (Report on Kapāʻula Gulch, 2009). There was little suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Lentipes concolor* (2,272 m) followed by *Atyoida bisulcata* (712 m), *Awaous guamensis* (477 m), *Neritina granosa* (459 m), and *Sicyopterus stimpsoni* (208 m). Only *Atyoida bisulcata* were observed in the stream surveys, but surveys were only conducted upstream of Hāna Highway (Report on Kapāʻula Gulch, 2009). In general, the loss of instream habitat due to water removal resulted in about 20% loss of habitat for these species. *Atyoida bisulcata* and *Lentipes concolor* were more affected by entrainment issues than the other species as they may migrate upstream of the diversion.

From a ranking perspective, Kapāʻula Gulch had less than average amounts of potential suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 4.1 km of habitat for all species combined in Kapāʻula Gulch with 50.4% of this lost due to the combined effects of the stream diversion. There is the potential to recover over 2 km of habitat units in this stream and it ranked twelfth among all streams in this report. Restoration of flow to improve fish passage at upstream sites would improve stream conditions for native species.

**Hanawī Stream:**

Hanawī Stream is narrow and steep with good stream flow downstream of Hāna Highway as the result of substantial spring water input (Report on Hanawī Stream, 2009). There were small amounts of suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis*, and *Macrobrachium grandimanus*. *Eleotris sandwicensis* was observed in the lowest section of this stream (Report on Hanawī Stream, 2009). For the climbing species, the most habitat was predicted for *Lentipes concolor* (2,728 m) followed by *Atyoida bisulcata* (1,306 m), *Neritina granosa* (1,006 m), *Awaous guamensis* (967 m), and *Sicyopterus stimpsoni* (835 m). All of the climbing species were observed in the stream surveys with both adult and juveniles present (Report on Hanawī Stream, 2009). Hanawī Stream had little loss of stream habitat due to the stream diversion. Most of the loss of habitat was associated with *Lentipes concolor* and *Atyoida bisulcata* that were affected by entrainment issues. While Hanawī Stream has good populations of native species, passage of the diversion would provide at connection to additional habitat upstream. The large amount of spring flow into Hanawī Stream likely provides long term habitat stability not found in the more runoff dominated streams and has resulted in robust native animal populations.

From a ranking perspective, Hanawī Stream had more than average amounts of potential suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 7.5 km of habitat for all species combined in Hanawī Stream with 45.6% of this lost due to the entrainment by the stream diversion. There is the potential to recover almost 3.4 km of habitat units in this stream and it ranked tenth among all streams in this report. Restoration of flow to improve fish passage would improve stream conditions for native species.

**Makapipi Stream:**

Makapipi Stream is small and steep with no embayment (Report on Makapipi Stream, 2009). There was little suitable habitat predicted for the non-climbing animals which included *Stenogobius hawaiiensis*, *Eleotris sandwicensis,* and *Macrobrachium grandimanus*. For the climbing species, the most habitat was predicted for *Lentipes concolor* (2,728 m) followed by *Atyoida bisulcata* (1,306 m), *Neritina granosa* (1,006 m), *Awaous guamensis* (967 m), and *Sicyopterus stimpsoni* (835 m). Only *Lentipes concolor* and *Atyoida bisulcata* were observed in the stream surveys and habitat was generally considered poor due to water removal in stream sections below the diversion (Report on Makapipi Stream, 2009). The HSHEP model results predicted a loss of about 20 to 40% of instream habitat due to water removal. The stream surveys indicated this may be an underestimation. *Lentipes concolor* and *Atyoida bisulcata* likely pass the diversion and are thus more affected by entrainment issues than the other species.

From a ranking perspective, Makapipi Stream had more than average amounts of potential suitable habitat for native species in comparison with the other streams in this analysis. Overall, the results of the HSHEP model predicted approximately 6.9 km of habitat for all species combined in Makapipi Stream with 54.6% of this lost due to the combined effects of the stream diversion. There is the potential to recover almost 3.8 km of habitat units in this stream and it ranked eighth among all streams in this report. Restoration of flow to increase local habitat and improve fish passage would improve stream conditions for native species.

**Prioritization of restoration efforts:**

In addition to assessing habitat for each species in each stream, the HSHEP model allowed the effect of each diversion to be considered with respect to all diversions. Each diversion and its separate effect on loss of instream habitat or entrainment of migrating individuals was ranked due to its overall loss of habitat for the combined group of native stream animals (Table 13).

When viewing the results of the diversion ranking, it becomes apparent that the restoration of fish passage and restoration of suitable habitat forming flows at a small number of key locations can result in large amounts of potential habitat to become available for native animals. For example, restoration of ecological function (either fish passage or instream habitat) at the top ten locations could return almost 50% of the currently unavailable habitat to the stream animals. The top 20 sites would return 75% and the top 25 would return 84% of the habitat. The number one recommended action would be to return water to lower Honomanū Stream. This action alone would result in a gain of 8.3 km of habitat for a range of species and represents 12.4% of the total possible restored habitats. It also demonstrates how the restoration of an upstream diversion is not useful without first improving diversions downstream.

**General Conclusions:**

The streams of northeast Maui in this analysis had a range of surface water diversions affecting their stream flow and, therefore, the amount of instream habitat for native amphidromous animals. Some streams had no major diversions, many had moderate levels of diversions, and few had extensive amounts of stream flow diversions. In most cases where diversions did occur, the diversions blocked the stream and captured 100% of the stream flow at low and moderate rates of discharge. Typically, downstream of the diversion a stream gradually gained water and returned to a continuous flowing stream. In some streams, especially in the western extent of the study area, streams were diverted at multiple elevations.

In general, the prediction of habitat availability resulting from the HSHEP model had good fit with the observed conditions in the field. The HSHEP model provides a standardized method to compare both streams as a whole and sites within a stream for all species of concern. As a result, a prioritization of the specific type and location of restoration efforts was developed. Given the importance of freshwater for human use, using the results of HSHEP to provide guidance in choosing the most effective management actions aimed at improving instream habitat. While this report focused the use of the HSHEP on a specific group of streams, the model was developed from statewide data and can be applied to any or all streams in the state. This gives DAR the ability to develop statewide management and restoration targets for native animals in Hawaiian streams. The modeling process also opens the door to more sophisticated habitat mitigation strategies. For example, if unavoidable development of stream resources results in a loss of habitat in one stream, it is possible to restore comparable amounts of suitable stream habitats in another stream to offset the loss. The HSHEP modeling effort is the result of a long term commitment of DAR to manage, protect, and enhance the states aquatic resources and in collaboration with Bishop Museum to help synthesize the vast amount of information gathered by the State.

The application of the HSHEP model on the prioritization of restoration sites is a first for the management of Hawaiian streams and their native biota. The HSHEP model is the first to integrate amphidromous life history requirements of the animals with site, reach, stream, region, and island based characteristics while applying all of the available data on the locations and habitat use collected statewide. As a result, the HSHEP is truly an oceanic island model for management of stream ecosystems. It is our intent for the HSHEP model to provide a more structured and transparent method to understand the consequences of humans' manipulation of the stream environment.

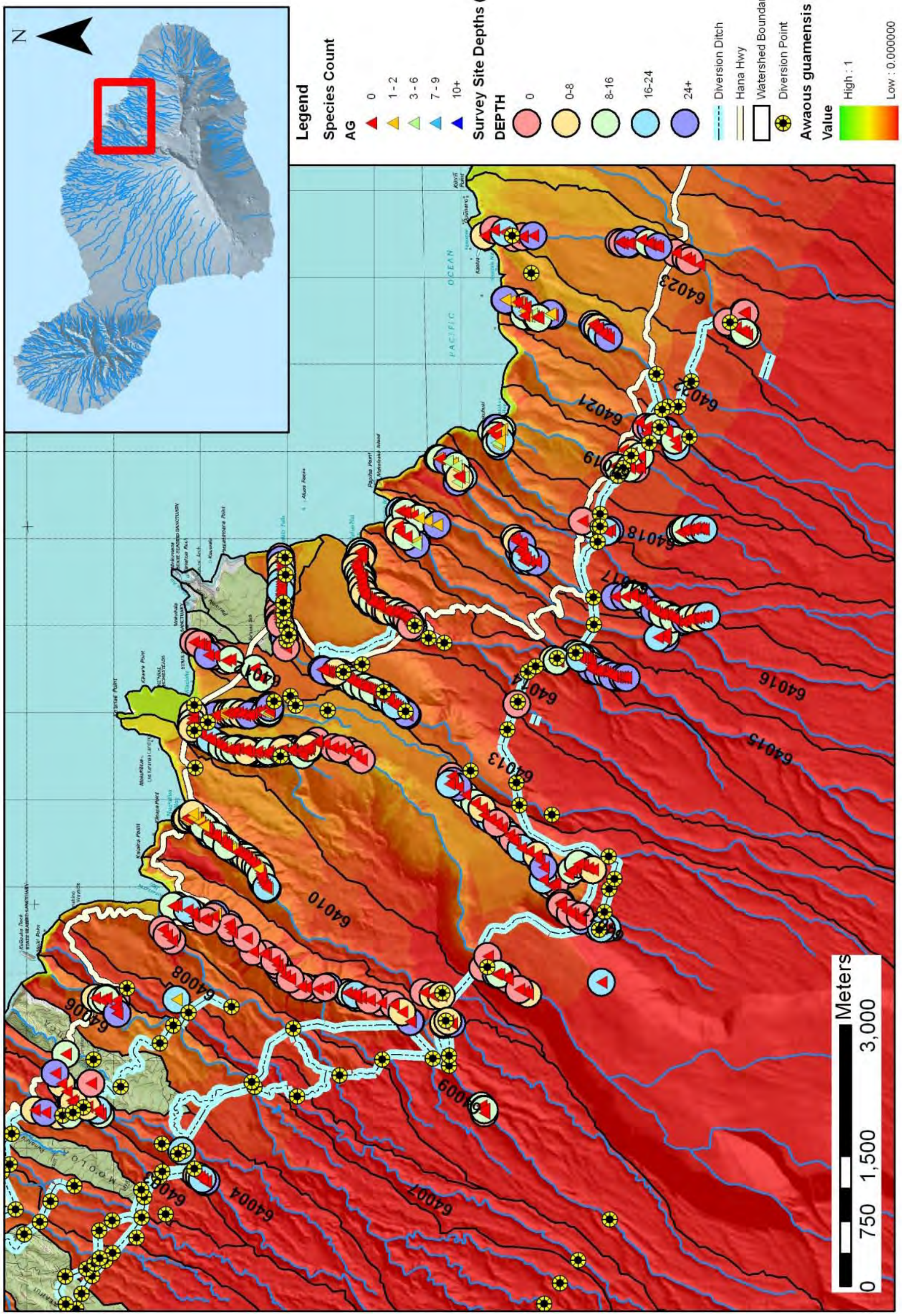


Figure 57. Predicted Habitat Suitability Index (HSI) for *Awaous guamensis*. Map includes survey site depths and count of *Awaous guamensis* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

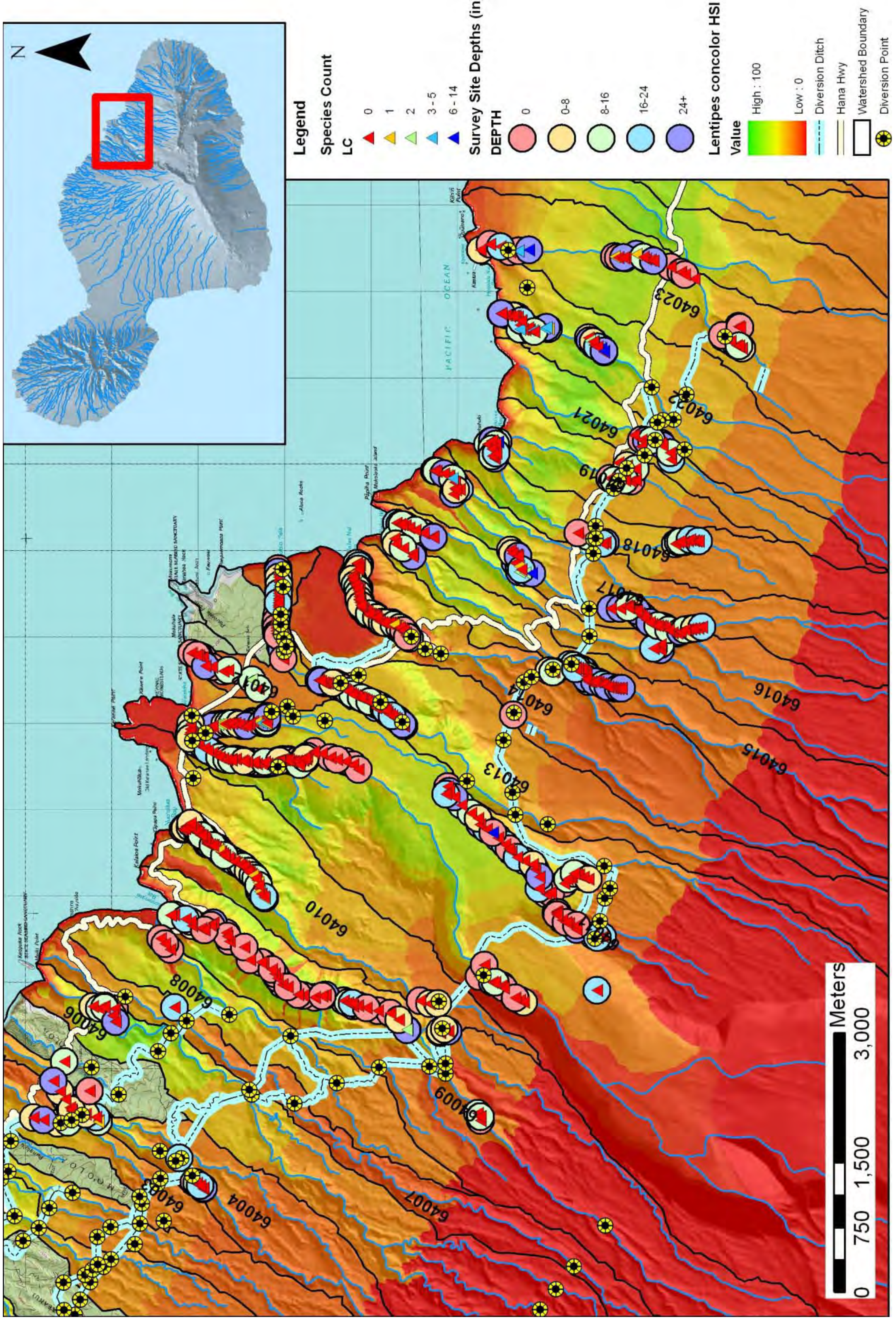


Figure 58. Predicted Habitat Suitability Index (HSI) for *Lentipes concolor*. Map includes survey site depths and count of *Lentipes concolor* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

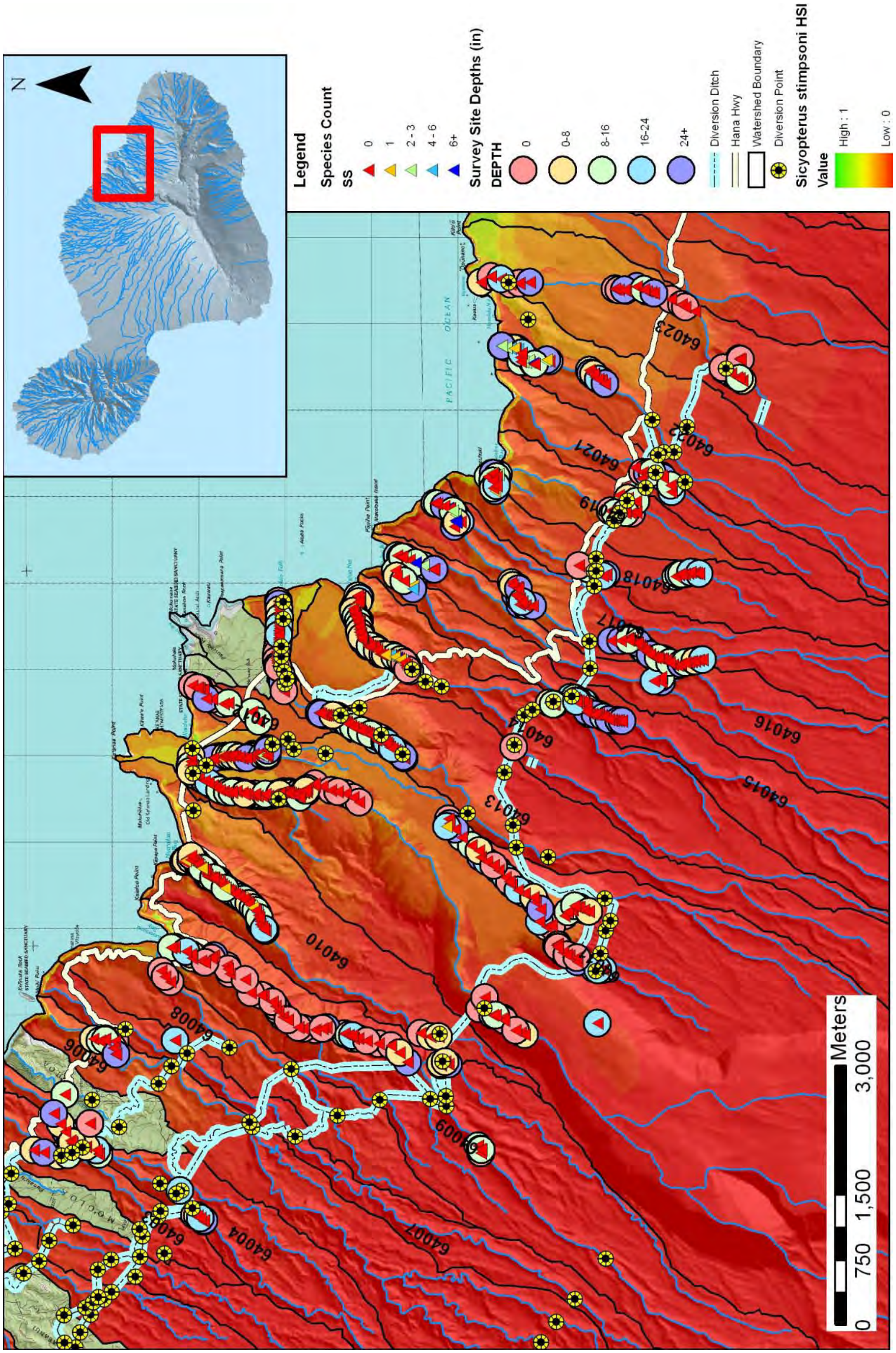


Figure 59. Predicted Habitat Suitability Index (HSI) for *Sicyopterus stimpsoni*. Map includes survey site depths and count of *Sicyopterus stimpsoni* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

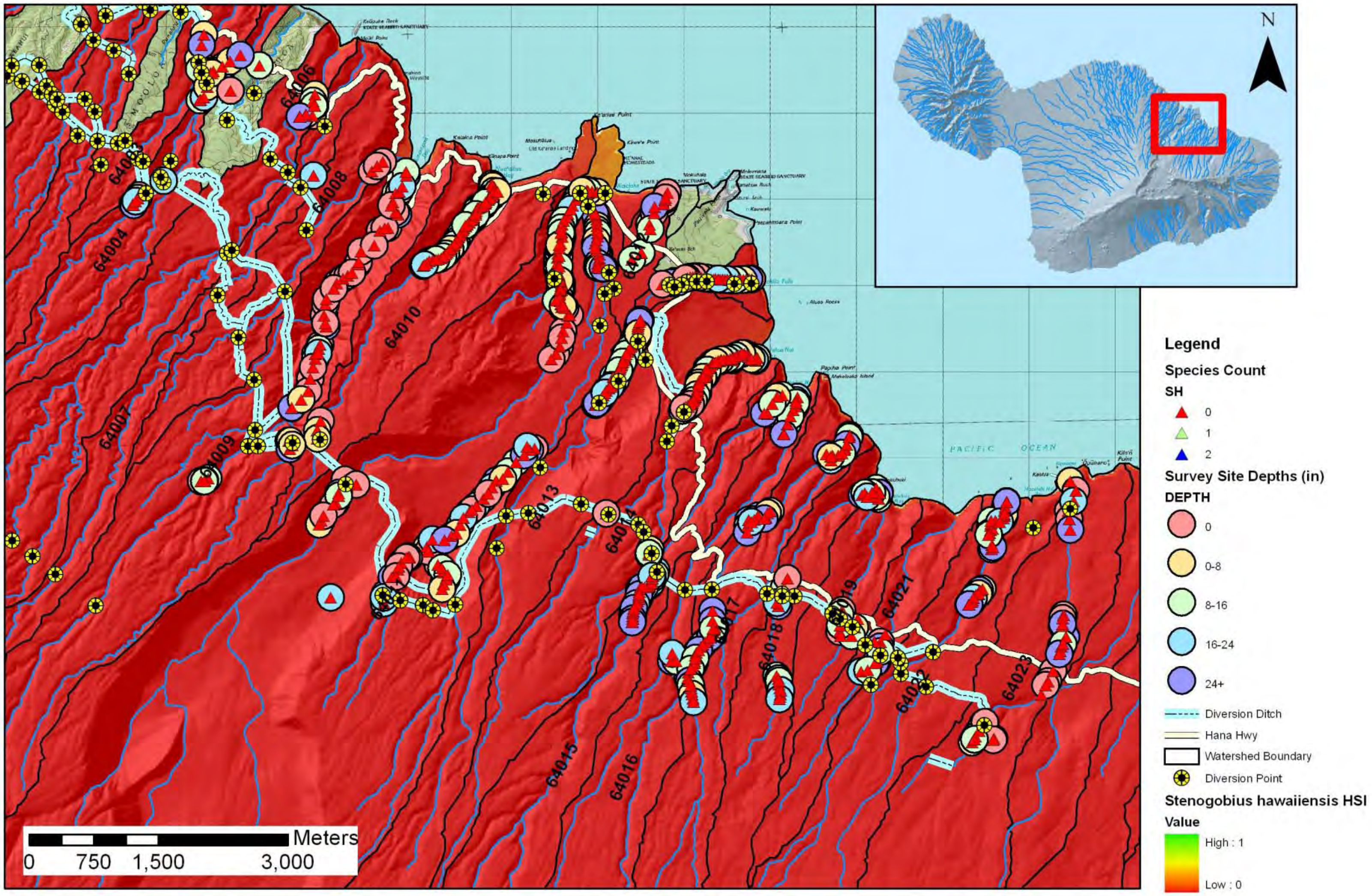


Figure 60. Predicted Habitat Suitability Index (HSI) for *Stenogobius hawaiiensis.* Map includes survey site depths and count of *Stenogobius hawaiiensis* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

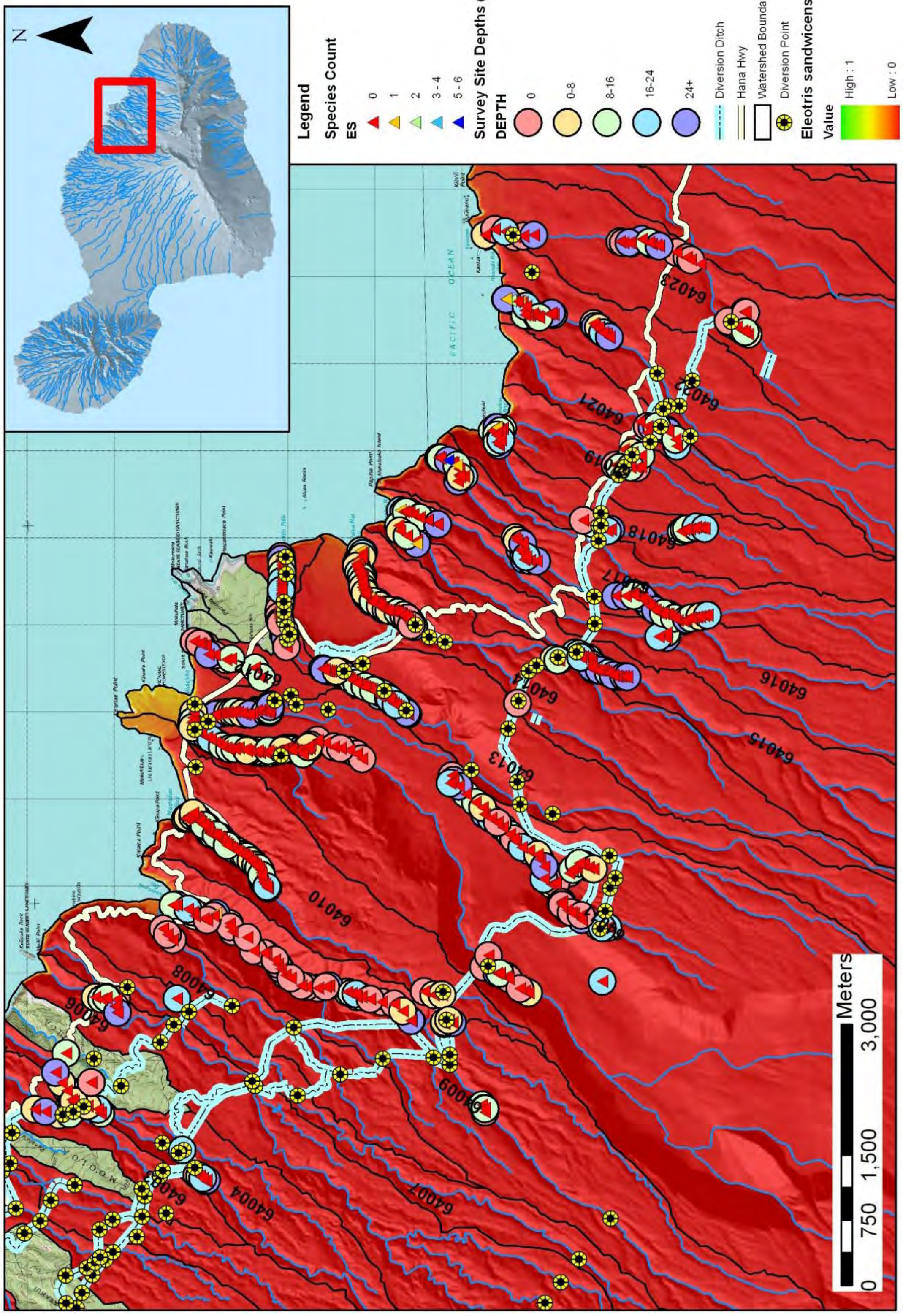


Figure 61. Predicted Habitat Suitability Index (HSI) for *Eleotris sandwicensis*. Map includes survey site depths and count of *Eleotris sandwicensis* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

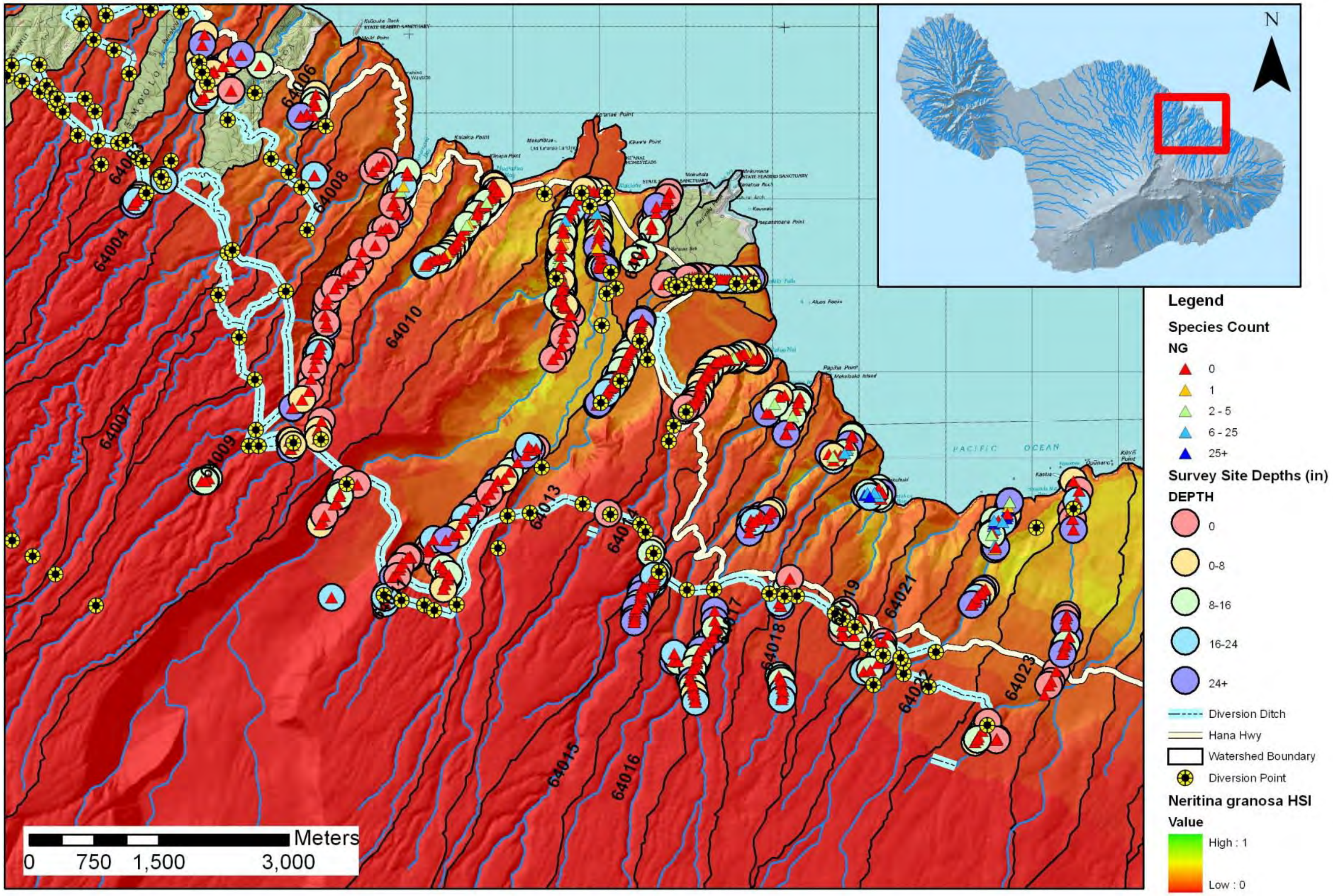


Figure 62. Predicted Habitat Suitability Index (HSI) for *Neritina granosa.* Map includes survey site depths and count of *Neritina granosa* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

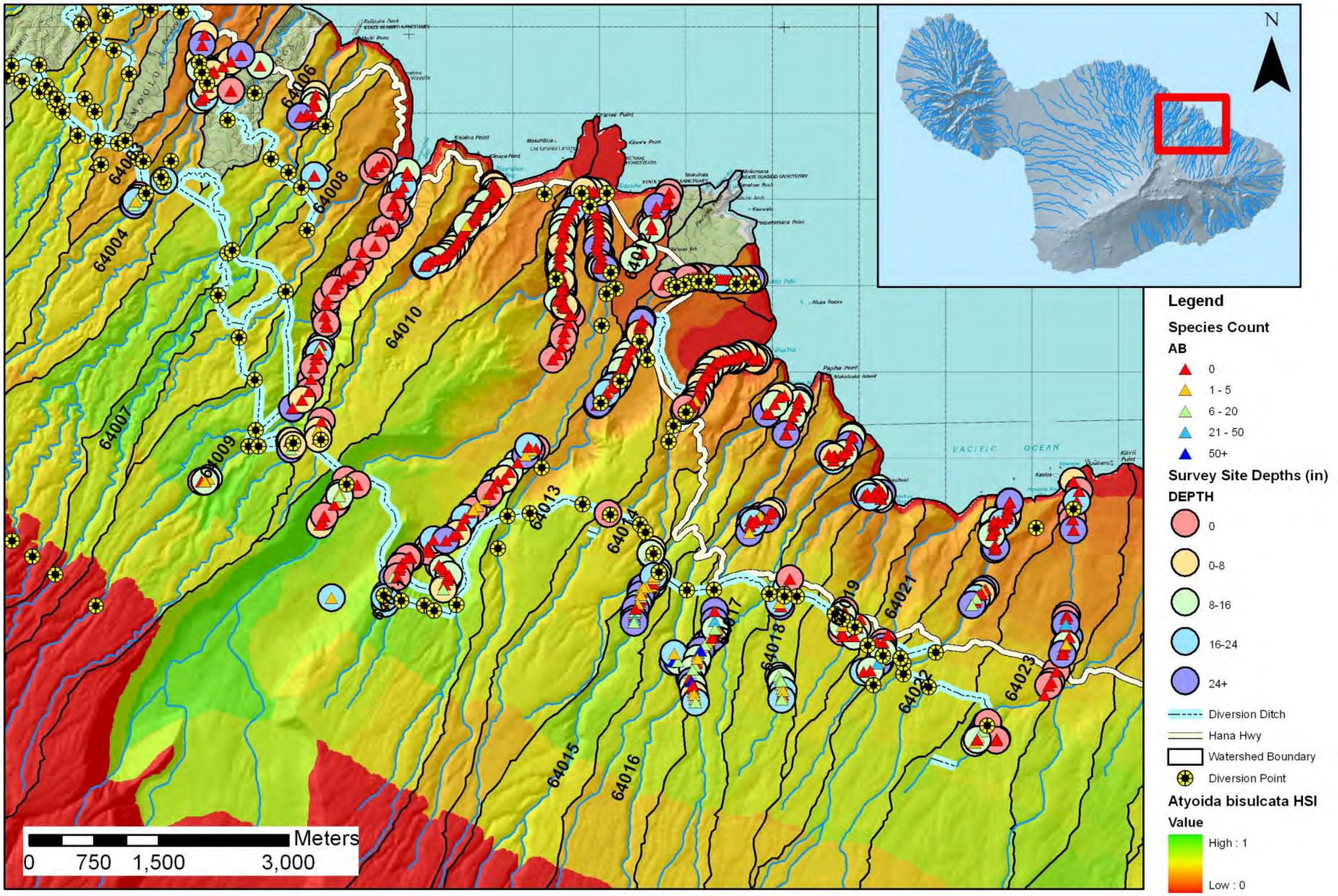


Figure 63. Predicted Habitat Suitability Index (HSI) for *Atyoida bisulcata.* Map includes survey site depths and count of *Atyoida bisulcata* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

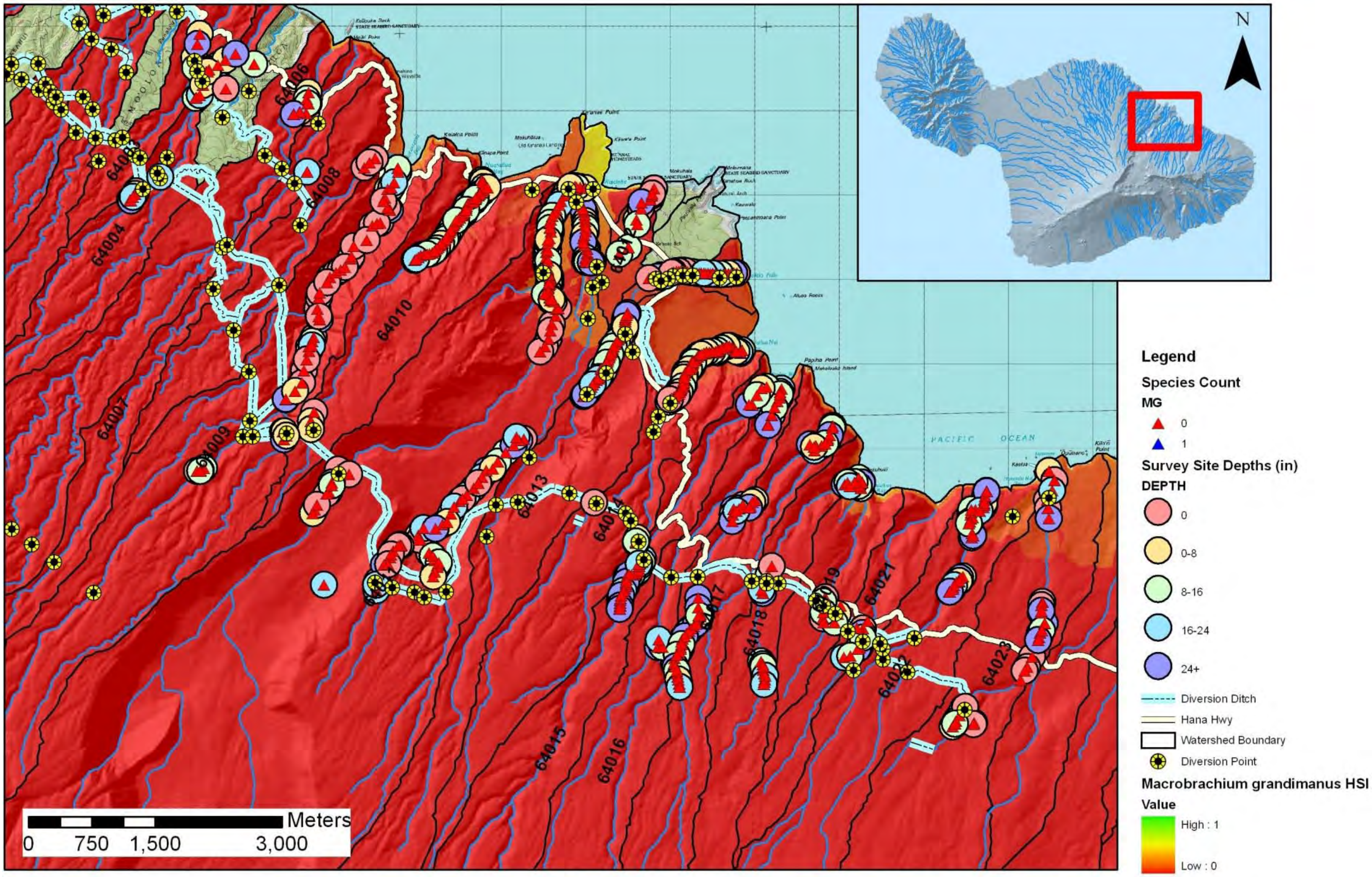


Figure 64. Predicted Habitat Suitability Index (HSI) for *Macrobrachium grandimanus*. Map includes survey site depths and count of *Macrobrachium grandimanus* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

Table 4. Summary of the amount of habitat units for *Awaous guamensis* (AG). Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | AG Habitat Units (HU) in Stream | AG HU after flow diversion (FD) | AG HU after FD + Upstream Migration Barriers (UpMB) | AG HU after FD + UpMB + Downstream Migration Barriers (DownMB) | AG HU Lost | AG HU Lost Rank | % AG HU lost of stream total | % AG HU lost of stream total Rank | % AG HU lost to FD | % AG HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 295 | 229 | 129 | 108 | 187 | 10 | 63.2% | 5 | 22.4% | 11 |
| Waikamoi | 64004 | 462 | 202 | 30 | 9 | 453 | 3 | 98.1% | 2 | 56.3% | 2 |
| Puohokamoa | 64006 | 1,190 | 608 | 450 | 428 | 762 | 2 | 64.0% | 4 | 48.9% | 5 |
| Haipuaʻena | 64007 | 124 | 63 | 51 | 48 | 76 | 13 | 61.2% | 6 | 49.5% | 4 |
| Punalau | 64008 | 604 | 359 | 238 | 214 | 390 | 5 | 64.5% | 3 | 40.5% | 7 |
| Honomanū | 64009 | 1,689 | 0 | 0 | 0 | 1,689 | 1 | 100.0% | 1 | 100.0% | 1 |
| Nuaʻailua | 64010 | 1,076 | 1,076 | 1,076 | 1,076 | 0 | 15 | 0.0% | 15 | 0.0% | 14 |
| ʻŌhiʻa | 64012 | 228 | 228 | 228 | 228 | 0 | 15 | 0.0% | 15 | 0.0% | 14 |
| W. Wailua Iki | 64015 | 500 | 247 | 229 | 225 | 275 | 8 | 55.0% | 7 | 50.6% | 3 |
| E. Wailua Iki | 64016 | 717 | 391 | 361 | 355 | 362 | 7 | 50.5% | 8 | 45.5% | 6 |
| Kopiliʻula | 64017 | 1,004 | 693 | 643 | 633 | 371 | 6 | 36.9% | 11 | 30.9% | 10 |
| Waiohue | 64018 | 579 | 349 | 314 | 307 | 272 | 9 | 47.0% | 9 | 39.7% | 8 |
| Paakea Gulch | 64019 | 770 | 748 | 699 | 689 | 80 | 12 | 10.4% | 13 | 2.8% | 13 |
| Kapāʻula Gulch | 64021 | 477 | 371 | 344 | 338 | 139 | 11 | 29.1% | 12 | 22.3% | 12 |
| Hanawī | 64022 | 795 | 795 | 738 | 727 | 68 | 14 | 8.5% | 14 | 0.0% | 14 |
| Makapipi | 64023 | 967 | 600 | 579 | 575 | 392 | 4 | 40.5% | 10 | 37.9% | 9 |

Table 5. Summary of the amount of habitat units for *Lentipes concolor* (LC). Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | LC Habitat Units (HU) in Stream | LC HU after flow diversion (FD) | LC HU after FD + Upstream Migration Barriers (UpMB) | LC HU after FD + UpMB + Downstream Migration Barriers (DownMB) | LC HU Lost | LC HU Lost Rank | % LC HU lost of stream total | % LC HU lost of stream total Rank | % LC HU lost to FD | % LC HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 1,136 | 925 | 449 | 354 | 783 | 13 | 68.9% | 7 | 18.6% | 11 |
| Waikamoi | 64004 | 3,558 | 1,877 | 148 | 33 | 3,524 | 3 | 99.1% | 2 | 47.2% | 3 |
| Puohokamoa | 64006 | 5,094 | 2,732 | 929 | 803 | 4,291 | 1 | 84.2% | 3 | 46.4% | 4 |
| Haipua‘ena | 64007 | 1,682 | 841 | 442 | 398 | 1,284 | 10 | 76.3% | 5 | 50.0% | 2 |
| Punalau | 64008 | 2,257 | 1,772 | 612 | 450 | 1,807 | 6 | 80.1% | 4 | 21.5% | 9 |
| Honomanū | 64009 | 3,844 | 1,155 | 77 | 8 | 3,836 | 2 | 99.8% | 1 | 69.9% | 1 |
| Nua‘ailua | 64010 | 1,711 | 1,711 | 1,506 | 1,465 | 246 | 15 | 14.4% | 15 | 0.0% | 14 |
| ‘Ōhi‘a | 64012 | 78 | 78 | 78 | 78 | 0 | 16 | 0.0% | 16 | 0.0% | 14 |
| W. Wailua Iki | 64015 | 2,255 | 1,489 | 842 | 712 | 1,543 | 9 | 68.4% | 8 | 34.0% | 5 |
| E. Wailua Iki | 64016 | 2,589 | 1,931 | 956 | 761 | 1,827 | 5 | 70.6% | 6 | 25.4% | 7 |
| Kopili‘ula | 64017 | 3,871 | 3,082 | 1,898 | 1,661 | 2,209 | 4 | 57.1% | 10 | 20.4% | 10 |
| Waiohue | 64018 | 1,895 | 1,447 | 765 | 628 | 1,266 | 11 | 66.8% | 9 | 23.7% | 8 |
| Paakea Gulch | 64019 | 1,732 | 1,695 | 1,298 | 1,219 | 513 | 14 | 29.6% | 14 | 2.1% | 13 |
| Kapā‘ula Gulch | 64021 | 2,272 | 1,936 | 1,240 | 1,100 | 1,172 | 12 | 51.6% | 12 | 14.8% | 12 |
| Hanawī | 64022 | 3,173 | 3,173 | 1,869 | 1,609 | 1,564 | 7 | 49.3% | 13 | 0.0% | 14 |
| Makapipi | 64023 | 2,728 | 1,992 | 1,319 | 1,184 | 1,544 | 8 | 56.6% | 11 | 27.0% | 6 |

Table 6. Summary of the amount of habitat units for *Stenogobious hawaiiensis* (SH). Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | SH Habitat Units (HU) in Stream | SH HU after flow diversion (FD) | SH HU after FD + Upstream Migration Barriers (UpMB) | SH HU after FD + UpMB + Downstream Migration Barriers (DownMB) | SH HU Lost | SH HU Lost Rank | % SH HU lost of stream total | % SH HU lost of stream total Rank | % SH HU lost to FD | % SH HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 11 | 0.0% | 11 | 0.0% | 11 |
| Waikamoi | 64004 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 11 | 0.0% | 11 | 0.0% | 11 |
| Puohokamoa | 64006 | 7.7 | 4.1 | 4.1 | 4.1 | 3.6 | 5 | 47.0% | 5 | 47.0% | 5 |
| Haipua‘ena | 64007 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 11 | 0.0% | 11 | 0.0% | 11 |
| Punalau | 64008 | 15.9 | 7.3 | 7.3 | 7.3 | 8.6 | 2 | 54.0% | 2 | 54.0% | 2 |
| Honomanū | 64009 | 153.3 | 0.0 | 0.0 | 0.0 | 153.3 | 1 | 100.0% | 1 | 100.0% | 1 |
| Nua‘ailua | 64010 | 13.7 | 13.7 | 13.7 | 13.7 | 0.0 | 11 | 0.0% | 11 | 0.0% | 11 |
| ‘Ōhi‘a | 64012 | 1.2 | 1.2 | 1.2 | 1.2 | 0.0 | 11 | 0.0% | 11 | 0.0% | 11 |
| W. Wailua Iki | 64015 | 7.7 | 3.6 | 3.6 | 3.6 | 4.1 | 4 | 53.0% | 3 | 53.0% | 3 |
| E. Wailua Iki | 64016 | 10.9 | 5.7 | 5.7 | 5.7 | 5.2 | 3 | 48.0% | 4 | 48.0% | 4 |
| Kopili‘ula | 64017 | 10.6 | 7.1 | 7.1 | 7.1 | 3.5 | 6 | 33.0% | 8 | 33.0% | 8 |
| Waiohue | 64018 | 3.1 | 1.8 | 1.8 | 1.8 | 1.3 | 8 | 43.0% | 6 | 43.0% | 6 |
| Paakea Gulch | 64019 | 3.3 | 3.2 | 3.2 | 3.2 | 0.1 | 10 | 3.0% | 10 | 3.0% | 10 |
| Kapā‘ula Gulch | 64021 | 0.5 | 0.4 | 0.4 | 0.4 | 0.1 | 9 | 24.0% | 9 | 24.0% | 9 |
| Hanawī | 64022 | 2.9 | 2.9 | 2.9 | 2.9 | 0.0 | 11 | 0.0% | 11 | 0.0% | 11 |
| Makapipi | 64023 | 3.4 | 2.1 | 2.1 | 2.1 | 1.3 | 7 | 39.0% | 7 | 39.0% | 7 |

Table 7. Summary of the amount of habitat units for *Sicyopterus stimpsoni* (SS). Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | SS Habitat Units (HU) in Stream | SS HU after flow diversion (FD) | SS HU after FD + Upstream Migration Barriers (UpMB) | SS HU after FD + UpMB + Downstream Migration Barriers (DownMB) | SS HU Lost | SS HU Lost Rank | % SS HU lost of stream total | % SS HU lost of stream total Rank | % SS HU lost to FD | % SS HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 190 | 142 | 88 | 77 | 112 | 10 | 59.2% | 4 | 25.2% | 11 |
| Waikamoi | 64004 | 288 | 118 | 19 | 6 | 282 | 6 | 97.8% | 2 | 59.0% | 2 |
| Puohokamoa | 64006 | 821 | 423 | 349 | 339 | 482 | 2 | 58.8% | 5 | 48.5% | 5 |
| Haipuaʻena | 64007 | 117 | 60 | 51 | 49 | 68 | 11 | 58.2% | 6 | 48.8% | 4 |
| Punalau | 64008 | 370 | 208 | 151 | 141 | 229 | 8 | 62.0% | 3 | 43.9% | 7 |
| Honomanū | 64009 | 1,199 | 0 | 0 | 0 | 1,199 | 1 | 100.0% | 1 | 100.0% | 1 |
| Nuaʻailua | 64010 | 879 | 879 | 873 | 872 | 7 | 15 | 0.8% | 15 | 0.0% | 14 |
| ʻŌhiʻa | 64012 | 231 | 231 | 231 | 231 | 0 | 16 | 0.0% | 16 | 0.0% | 14 |
| W. Wailua Iki | 64015 | 423 | 202 | 197 | 196 | 226 | 9 | 53.5% | 7 | 52.3% | 3 |
| E. Wailua Iki | 64016 | 813 | 449 | 405 | 396 | 416 | 3 | 51.2% | 8 | 44.8% | 6 |
| Kopiliʻula | 64017 | 1,021 | 701 | 660 | 651 | 369 | 4 | 36.2% | 11 | 31.3% | 10 |
| Waiohue | 64018 | 521 | 309 | 287 | 282 | 239 | 7 | 45.8% | 9 | 40.7% | 8 |
| Paakea Gulch | 64019 | 665 | 646 | 606 | 598 | 67 | 12 | 10.0% | 13 | 2.8% | 13 |
| Kapāʻula Gulch | 64021 | 208 | 161 | 151 | 149 | 59 | 13 | 28.3% | 12 | 22.6% | 12 |
| Hanawī | 64022 | 631 | 631 | 599 | 592 | 38 | 14 | 6.1% | 14 | 0.0% | 14 |
| Makapipi | 64023 | 835 | 517 | 501 | 498 | 337 | 5 | 40.4% | 10 | 38.1% | 9 |

Table 8. Summary of the amount of habitat units for *Eleotris sandwicensis* (ES). Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | ES Habitat Units (HU) in Stream | ES HU after flow diversion (FD) | ES HU after FD + Upstream Migration Barriers (UpMB) | ES HU after FD + UpMB + Downstream Migration Barriers (DownMB) | ES HU Lost | ES HU Lost Rank | % ES HU lost of stream total | % ES HU lost of stream total Rank | % ES HU lost to FD | % ES HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 0.5 | 0.3 | 0.3 | 0.3 | 0.2 | 13 | 39.0% | 9 | 39.0% | 9 |
| Waikamoi | 64004 | 0.5 | 0.1 | 0.0 | 0.0 | 0.5 | 10 | 95.5% | 2 | 82.0% | 2 |
| Puohokamoa | 64006 | 32.1 | 17.0 | 17.0 | 17.0 | 15.1 | 4 | 47.0% | 6 | 47.0% | 6 |
| Haipuaʻena | 64007 | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 | 12 | 46.0% | 7 | 46.0% | 7 |
| Punalau | 64008 | 52.8 | 24.3 | 24.3 | 24.3 | 28.5 | 2 | 54.0% | 3 | 54.0% | 3 |
| Honomanū | 64009 | 192.4 | 0.0 | 0.0 | 0.0 | 192.4 | 1 | 100.0% | 1 | 100.0% | 1 |
| Nuaʻailua | 64010 | 74.6 | 74.6 | 74.6 | 74.6 | 0.0 | 14 | 0.0% | 14 | 0.0% | 14 |
| ʻŌhiʻa | 64012 | 9.4 | 9.4 | 9.4 | 9.4 | 0.0 | 14 | 0.0% | 14 | 0.0% | 14 |
| W. Wailua Iki | 64015 | 24.2 | 11.4 | 11.4 | 11.4 | 12.8 | 5 | 53.0% | 4 | 53.0% | 4 |
| E. Wailua Iki | 64016 | 32.2 | 16.7 | 16.7 | 16.7 | 15.5 | 3 | 48.0% | 5 | 48.0% | 5 |
| Kopiliʻula | 64017 | 38.2 | 25.6 | 25.6 | 25.6 | 12.6 | 6 | 33.0% | 11 | 33.0% | 11 |
| Waiohue | 64018 | 20.8 | 11.8 | 11.8 | 11.8 | 8.9 | 7 | 43.0% | 8 | 43.0% | 8 |
| Paakea Gulch | 64019 | 11.8 | 11.4 | 11.4 | 11.4 | 0.4 | 11 | 3.0% | 13 | 3.0% | 13 |
| Kapāʻula Gulch | 64021 | 2.9 | 2.2 | 2.2 | 2.2 | 0.7 | 9 | 24.0% | 12 | 24.0% | 12 |
| Hanawī | 64022 | 14.3 | 14.3 | 14.3 | 14.3 | 0.0 | 14 | 0.0% | 14 | 0.0% | 14 |
| Makapipi | 64023 | 19.7 | 12.0 | 12.0 | 12.0 | 7.7 | 8 | 39.0% | 9 | 39.0% | 10 |

Table 9. Summary of the amount of habitat units for *Neritina granosa* (NG). Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | NG Habitat Units (HU) in Stream | NG HU after flow diversion (FD) | NG HU after FD + Upstream Migration Barriers (UpMB) | NG HU after FD + UpMB + Downstream Migration Barriers (DownMB) | NG HU Lost | NG HU Lost Rank | % NG HU lost of stream total | % NG HU lost of stream total Rank | % NG HU lost to FD | % NG HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 348 | 249 | 174 | 159 | 189 | 10 | 54.2% | 7 | 28.6% | 11 |
| Waikamoi | 64004 | 579 | 212 | 41 | 15 | 564 | 3 | 97.4% | 2 | 63.4% | 2 |
| Puohokamoa | 64006 | 1,239 | 640 | 511 | 495 | 744 | 2 | 60.1% | 4 | 48.3% | 4 |
| Haipuaʻena | 64007 | 288 | 149 | 130 | 126 | 162 | 11 | 56.2% | 5 | 48.2% | 5 |
| Punalau | 64008 | 458 | 272 | 180 | 163 | 295 | 7 | 64.4% | 3 | 40.6% | 7 |
| Honomanū | 64009 | 950 | 0 | 0 | 0 | 950 | 1 | 100.0% | 1 | 100.0% | 1 |
| Nuaʻailua | 64010 | 801 | 801 | 801 | 801 | 0 | 15 | 0.0% | 15 | 0.0% | 14 |
| ʻŌhiʻa | 64012 | 137 | 137 | 137 | 137 | 0 | 15 | 0.0% | 15 | 0.0% | 14 |
| W. Wailua Iki | 64015 | 425 | 206 | 196 | 194 | 231 | 9 | 54.3% | 6 | 51.4% | 3 |
| E. Wailua Iki | 64016 | 787 | 426 | 398 | 393 | 394 | 6 | 50.1% | 8 | 45.9% | 6 |
| Kopiliʻula | 64017 | 1,115 | 764 | 724 | 717 | 399 | 5 | 35.8% | 11 | 31.6% | 10 |
| Waiohue | 64018 | 621 | 369 | 341 | 335 | 285 | 8 | 46.0% | 9 | 40.6% | 8 |
| Paakea Gulch | 64019 | 831 | 807 | 775 | 768 | 62 | 13 | 7.5% | 13 | 2.9% | 13 |
| Kapāʻula Gulch | 64021 | 459 | 354 | 338 | 335 | 124 | 12 | 27.1% | 12 | 23.0% | 12 |
| Hanawī | 64022 | 885 | 885 | 847 | 839 | 46 | 14 | 5.2% | 14 | 0.0% | 14 |
| Makapipi | 64023 | 1,006 | 622 | 604 | 601 | 405 | 4 | 40.2% | 10 | 38.1% | 9 |

Table 10. Summary of the amount of habitat units for *Atyoida bisulcata* (AB). Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | AB Habitat Units (HU) in Stream | AB HU after flow diversion (FD) | AB HU after FD + Upstream Migration Barriers (UpMB) | AB HU after FD + UpMB + Downstream Migration Barriers (DownMB) | AB HU Lost | AB HU Lost Rank | % AB HU lost of stream total | % AB HU lost of stream total Rank | % AB HU lost to FD | % AB HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 140 | 132 | 43 | 25 | 115 | 15 | 82.3% | 13 | 5.6% | 6 |
| Waikamoi | 64004 | 2,193 | 1,560 | 50 | 4 | 2,189 | 4 | 99.8% | 1 | 28.9% | 3 |
| Puohokamoa | 64006 | 3,450 | 2,390 | 169 | 63 | 3,387 | 3 | 98.2% | 3 | 30.7% | 2 |
| Haipua‘ena | 64007 | 3,755 | 2,447 | 324 | 173 | 3,582 | 2 | 95.4% | 4 | 34.8% | 1 |
| Punalau | 64008 | 777 | 758 | 109 | 44 | 733 | 10 | 94.3% | 5 | 2.5% | 12 |
| Honomanū | 64009 | 5,041 | 3,600 | 257 | 25 | 5,015 | 1 | 99.5% | 2 | 28.6% | 4 |
| Nua‘ailua | 64010 | 646 | 646 | 422 | 378 | 268 | 13 | 41.6% | 15 | 0.0% | 14 |
| ‘Ōhi‘a | 64012 | 1 | 1 | 1 | 1 | 0 | 16 | 0.0% | 16 | 0.0% | 14 |
| W. Wailua Iki | 64015 | 2,000 | 1,856 | 567 | 309 | 1,691 | 7 | 84.6% | 9 | 7.2% | 5 |
| E. Wailua Iki | 64016 | 1,477 | 1,415 | 378 | 171 | 1,306 | 8 | 88.4% | 6 | 4.2% | 10 |
| Kopili‘ula | 64017 | 2,078 | 1,971 | 616 | 345 | 1,734 | 6 | 83.4% | 10 | 5.2% | 8 |
| Waiohue | 64018 | 718 | 682 | 200 | 103 | 615 | 11 | 85.6% | 8 | 5.0% | 9 |
| Paakea Gulch | 64019 | 288 | 287 | 118 | 84 | 204 | 14 | 70.9% | 14 | 0.5% | 13 |
| Kapā‘ula Gulch | 64021 | 712 | 692 | 219 | 124 | 588 | 12 | 82.6% | 11 | 2.9% | 11 |
| Hanawī | 64022 | 2,003 | 2,003 | 553 | 263 | 1,739 | 5 | 86.8% | 7 | 0.0% | 14 |
| Makapipi | 64023 | 1,306 | 1,234 | 395 | 228 | 1,078 | 9 | 82.5% | 12 | 5.5% | 7 |

Table 11. Summary of the amount of habitat units for *Macrobrachium grandimanus* (MG). Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | MG Habitat Units (HU) in Stream | MG HU after flow diversion (FD) | MG HU after FD + Upstream Migration Barriers (UpMB) | MG HU after FD + UpMB + Downstream Migration Barriers (DownMB) | MG HU Lost | MG HU Lost Rank | % MG HU lost of stream total | % MG HU lost of stream total Rank | % MG HU lost to FD | % MG HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 0.9 | 0.5 | 0.5 | 0.5 | 0.3 | 12 | 39.0% | 8 | 39.0% | 8 |
| Waikamoi | 64004 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 13 | 0.0% | 13 | 0.0% | 13 |
| Puohokamoa | 64006 | 121.7 | 64.5 | 64.5 | 64.5 | 57.2 | 2 | 47.0% | 5 | 47.0% | 5 |
| Haipuaʻena | 64007 | 2.1 | 1.1 | 1.1 | 1.1 | 1.0 | 10 | 46.0% | 6 | 46.0% | 6 |
| Punalau | 64008 | 63.9 | 29.4 | 29.4 | 29.4 | 34.5 | 7 | 54.0% | 2 | 54.0% | 2 |
| Honomanū | 64009 | 447.4 | 0.0 | 0.0 | 0.0 | 447.4 | 1 | 100.0% | 1 | 100.0% | 1 |
| Nuaʻailua | 64010 | 133.5 | 133.5 | 133.5 | 133.5 | 0.0 | 13 | 0.0% | 13 | 0.0% | 13 |
| ʻŌhiʻa | 64012 | 37.9 | 37.9 | 37.9 | 37.9 | 0.0 | 13 | 0.0% | 13 | 0.0% | 13 |
| W. Wailua Iki | 64015 | 68.1 | 32.0 | 32.0 | 32.0 | 36.1 | 6 | 53.0% | 3 | 53.0% | 3 |
| E. Wailua Iki | 64016 | 102.2 | 53.1 | 53.1 | 53.1 | 49.0 | 3 | 48.0% | 4 | 48.0% | 4 |
| Kopiliʻula | 64017 | 118.8 | 79.6 | 79.6 | 79.6 | 39.2 | 4 | 33.0% | 10 | 33.0% | 10 |
| Waiohue | 64018 | 70.9 | 40.4 | 40.4 | 40.4 | 30.5 | 8 | 43.0% | 7 | 43.0% | 7 |
| Paakea Gulch | 64019 | 156.4 | 151.7 | 151.7 | 151.7 | 4.7 | 9 | 3.0% | 12 | 3.0% | 12 |
| Kapāʻula Gulch | 64021 | 3.4 | 2.6 | 2.6 | 2.6 | 0.8 | 11 | 24.0% | 11 | 24.0% | 11 |
| Hanawī | 64022 | 81.2 | 81.2 | 81.2 | 81.2 | 0.0 | 13 | 0.0% | 13 | 0.0% | 13 |
| Makapipi | 64023 | 93.7 | 57.2 | 57.2 | 57.2 | 36.5 | 5 | 39.0% | 8 | 39.0% | 8 |

Table 12. Summary of the combined total amount of habitat units for all native species in the analysis. This weights all native species equally in their conservation value, therefore, the total value is the sum of values for the eight native amphidromous species considered. Habitat Units (HU) are relative measures of stream habitat where each unit length of stream is multiplied by its suitability (range of 0 to 1) for a species resulting in a comparable measure of the linear amount of suitable stream habitat. HU have measures of stream size and watershed wetness incorporated into the value which reflect comparative stream width and as a result only linear measures of habitat area presented. All linear measures are in meters.

| Stream Name | Watershed ID | Total Habitat Units (HU) in Stream | Total HU after flow diversion (FD) | Total HU after FD + Upstream Migration Barriers (UpMB) | Total HU after FD + UpMB + Downstream Migration Barriers (DownMB) | Total HU Lost | Total HU Lost Rank | % HU lost of stream total | % HU lost of stream total Rank | % HU lost to FD | % HU lost to FD Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kōlea | 64003 | 2,111 | 1,678 | 884 | 725 | 1,386 | 13 | 65.7% | 8 | 20.5% | 11 |
| Waikamoi | 64004 | 7,080 | 3,969 | 287 | 68 | 7,013 | 3 | 99.0% | 2 | 43.9% | 2 |
| Puohokamoa | 64006 | 11,955 | 6,878 | 2,495 | 2,212 | 9,743 | 2 | 81.5% | 4 | 42.5% | 3 |
| Haipuaʻena | 64007 | 5,968 | 3,562 | 999 | 795 | 5,173 | 4 | 86.7% | 3 | 40.3% | 4 |
| Punalau | 64008 | 4,600 | 3,431 | 1,351 | 1,073 | 3,527 | 9 | 76.7% | 5 | 25.4% | 9 |
| Honomanū | 64009 | 13,516 | 4,755 | 334 | 33 | 13,483 | 1 | 99.8% | 1 | 64.8% | 1 |
| Nuaʻailua | 64010 | 5,335 | 5,335 | 4,900 | 4,813 | 521 | 15 | 9.8% | 15 | 0.0% | 14 |
| ʻŌhiʻa | 64012 | 723 | 723 | 723 | 723 | 0 | 16 | 0.0% | 16 | 0.0% | 14 |
| W. Wailua Iki | 64015 | 5,703 | 4,048 | 2,078 | 1,684 | 4,019 | 7 | 70.5% | 6 | 29.0% | 5 |
| E. Wailua Iki | 64016 | 6,528 | 4,687 | 2,575 | 2,152 | 4,375 | 6 | 67.0% | 7 | 28.2% | 6 |
| Kopiliʻula | 64017 | 9,257 | 7,323 | 4,653 | 4,119 | 5,138 | 5 | 55.5% | 10 | 20.9% | 10 |
| Waiohue | 64018 | 4,428 | 3,209 | 1,960 | 1,710 | 2,718 | 11 | 61.4% | 9 | 27.5% | 8 |
| Paakea Gulch | 64019 | 4,457 | 4,350 | 3,662 | 3,525 | 932 | 14 | 20.9% | 14 | 2.4% | 13 |
| Kapāʻula Gulch | 64021 | 4,135 | 3,518 | 2,296 | 2,051 | 2,084 | 12 | 50.4% | 12 | 14.9% | 12 |
| Hanawī | 64022 | 7,585 | 7,585 | 4,705 | 4,129 | 3,456 | 10 | 45.6% | 13 | 0.0% | 14 |
| Makapipi | 64023 | 6,958 | 5,036 | 3,470 | 3,156 | 3,801 | 8 | 54.6% | 11 | 27.6% | 7 |

Table 13. Ranked diversions sites by amount of habitat returned. Type is FD = Flow diversion or return of water for habitat and barrier = improve fish passage due to entrainment issues or lack of migratory pathway.

| Stream Name | Location | Watershed ID | Type | Habitat Units Lost | Rank | % Habitat Units Lost | Cumulative % Lost Habitat Units |
|---|---|---|---|---|---|---|---|
| Honomanū | Downstream D3 | 640095 | FD | 8,359 | 1 | 12.4% | 12.4% |
| Puohokamoa | Between D2 – D3 | 640063 | barrier | 3,862 | 2 | 5.7% | 18.1% |
| Hanawī | Upstream D1 | 640221 | barrier | 3,456 | 3 | 5.1% | 23.3% |
| Honomanū | Between D2 – D3 | 640093 | barrier | 3,233 | 4 | 4.8% | 28.1% |
| Kopiliʻula | Upstream D1 | 640171 | barrier | 3,203 | 5 | 4.8% | 32.8% |
| E. Wailua Iki | Upstream D1 | 640161 | barrier | 2,535 | 6 | 3.8% | 36.6% |
| Waikamoi | Between D2 – D3 | 640043 | barrier | 2,442 | 7 | 3.6% | 40.2% |
| W. Wailua Iki | Upstream D1 | 640151 | barrier | 2,364 | 8 | 3.5% | 43.7% |
| Puohokamoa | Between D2 – D3 | 640063 | FD | 2,151 | 9 | 3.2% | 46.9% |
| Haipuaʻena | Between D2 – D3 | 640073 | barrier | 2,009 | 10 | 3.0% | 49.9% |
| Kopiliʻula | Downstream D1 | 640175 | FD | 1,934 | 11 | 2.9% | 52.8% |
| Makapipi | Downstream D1 | 640235 | FD | 1,921 | 12 | 2.9% | 55.6% |
| Puohokamoa | Downstream D4 | 640065 | FD | 1,905 | 13 | 2.8% | 58.4% |
| Makapipi | Upstream D1 | 640231 | barrier | 1,880 | 14 | 2.8% | 61.2% |
| E. Wailua Iki | Downstream D1 | 640165 | FD | 1,841 | 15 | 2.7% | 64.0% |
| W. Wailua Iki | Downstream D1 | 640155 | FD | 1,656 | 16 | 2.5% | 66.4% |
| Waiohue | Upstream D1 | 640181 | barrier | 1,499 | 17 | 2.2% | 68.7% |
| Honomanū | Upstream D1 | 640091 | barrier | 1,489 | 18 | 2.2% | 70.9% |
| Kapāʻula Gulch | Upstream D1 | 640211 | barrier | 1,467 | 19 | 2.2% | 73.0% |
| Punalau | Between D3 – D4 | 640084 | barrier | 1,460 | 20 | 2.2% | 75.2% |
| Waikamoi | Between D3 – D4 | 640044 | barrier | 1,299 | 21 | 1.9% | 77.1% |
| Waikamoi | Between D2 – D3 | 640043 | FD | 1,219 | 22 | 1.8% | 78.9% |
| Waiohue | Downstream D1 | 640185 | FD | 1,219 | 23 | 1.8% | 80.8% |
| Punalau | Downstream D4 | 640085 | FD | 1,169 | 24 | 1.7% | 82.5% |
| Haipuaʻena | Between D2 – D3 | 640073 | FD | 1,084 | 25 | 1.6% | 84.1% |
| Puohokamoa | Between D3 – D4 | 640064 | FD | 1,020 | 26 | 1.5% | 85.6% |
| Waikamoi | Downstream D4 | 640045 | FD | 962 | 27 | 1.4% | 87.0% |
| Kōlea | Upstream D4 | 640034 | barrier | 953 | 28 | 1.4% | 88.5% |
| Waikamoi | Between D3 – D4 | 640044 | FD | 930 | 29 | 1.4% | 89.8% |
| Punalau | Upstream D3 | 640083 | barrier | 897 | 30 | 1.3% | 91.2% |
| Paakea Gulch | Upstream D1 | 640191 | barrier | 825 | 31 | 1.2% | 92.4% |
| Puohokamoa | Between D3 – D4 | 640064 | barrier | 804 | 32 | 1.2% | 93.6% |
| Haipuaʻena | Between D3 – D4 | 640074 | barrier | 757 | 33 | 1.1% | 94.7% |
| Haipuaʻena | Between D3 – D4 | 640074 | FD | 732 | 34 | 1.1% | 95.8% |

Table 13. continued.

| Stream Name | Location | Watershed ID | Type | Habitat Units Lost | Rank | % Habitat Units Lost | Cumulative % Lost Habitat Units |
|---|---|---|---|---|---|---|---|
| Kapāʻula Gulch | Downstream D1 | 640215 | FD | 617 | 35 | 0.9% | 96.7% |
| Haipuaʻena | Downstream D4 | 640075 | FD | 591 | 36 | 0.9% | 97.6% |
| Nuaʻailua | Upstream D1 | 640101 | barrier | 521 | 37 | 0.8% | 98.4% |
| Kōlea | Downstream D4 | 640035 | FD | 433 | 38 | 0.6% | 99.0% |
| Honomanū | Between D2 – D3 | 640093 | FD | 402 | 39 | 0.6% | 99.6% |
| Waikamoi | Downstream D4 | 640045 | barrier | 161 | 40 | 0.2% | 99.8% |
| Paakea Gulch | Downstream D1 | 640195 | FD | 107 | 41 | 0.2% | 100.0% |
| Kōlea | Upstream D4 | 640034 | FD | 0 | 42 | 0.0% | 100.0% |
| Kōlea | Downstream D4 | 640035 | barrier | 0 | 42 | 0.0% | 100.0% |
| Waikamoi | Upstream D1 | 640041 | barrier | 0 | 42 | 0.0% | 100.0% |
| Waikamoi | Upstream D1 | 640041 | FD | 0 | 42 | 0.0% | 100.0% |
| Waikamoi | Between D1 – D2 | 640042 | barrier | 0 | 42 | 0.0% | 100.0% |
| Waikamoi | Between D1 – D2 | 640042 | FD | 0 | 42 | 0.0% | 100.0% |
| Puohokamoa | Upstream D1 | 640061 | barrier | 0 | 42 | 0.0% | 100.0% |
| Puohokamoa | Upstream D1 | 640061 | FD | 0 | 42 | 0.0% | 100.0% |
| Puohokamoa | Between D1 – D2 | 640062 | barrier | 0 | 42 | 0.0% | 100.0% |
| Puohokamoa | Between D1 – D2 | 640062 | FD | 0 | 42 | 0.0% | 100.0% |
| Puohokamoa | Downstream D4 | 640065 | barrier | 0 | 42 | 0.0% | 100.0% |
| Haipuaʻena | Upstream D1 | 640071 | barrier | 0 | 42 | 0.0% | 100.0% |
| Haipuaʻena | Upstream D1 | 640071 | FD | 0 | 42 | 0.0% | 100.0% |
| Haipuaʻena | Between D1 – D2 | 640072 | barrier | 0 | 42 | 0.0% | 100.0% |
| Haipuaʻena | Between D1 – D2 | 640072 | FD | 0 | 42 | 0.0% | 100.0% |
| Haipuaʻena | Downstream D4 | 640075 | barrier | 0 | 42 | 0.0% | 100.0% |
| Punalau | Upstream D3 | 640083 | FD | 0 | 42 | 0.0% | 100.0% |
| Punalau | Between D3 – D4 | 640084 | FD | 0 | 42 | 0.0% | 100.0% |
| Punalau | Downstream D4 | 640085 | barrier | 0 | 42 | 0.0% | 100.0% |
| Honomanū | Upstream D1 | 640091 | FD | 0 | 42 | 0.0% | 100.0% |
| Honomanū | Between D1 – D2 | 640092 | barrier | 0 | 42 | 0.0% | 100.0% |
| Honomanū | Between D1 – D2 | 640092 | FD | 0 | 42 | 0.0% | 100.0% |
| Honomanū | Downstream D3 | 640095 | barrier | 0 | 42 | 0.0% | 100.0% |
| Nuaʻailua | Upstream D1 | 640101 | FD | 0 | 42 | 0.0% | 100.0% |
| Nuaʻailua | Downstream D1 | 640105 | barrier | 0 | 42 | 0.0% | 100.0% |
| Nuaʻailua | Downstream D1 | 640105 | FD | 0 | 42 | 0.0% | 100.0% |
| ʻŌhiʻa | Downstream D1 | 640125 | barrier | 0 | 42 | 0.0% | 100.0% |

Table 13. continued.

| Stream Name | Location | Watershed ID | Type | Habitat Units Lost | Rank | % Habitat Units Lost | Cumulative % Lost Habitat Units |
|---|---|---|---|---|---|---|---|
| W. Wailua Iki | Upstream D1 | 640151 | FD | 0 | 42 | 0.0% | 100.0% |
| W. Wailua Iki | Downstream D1 | 640155 | barrier | 0 | 42 | 0.0% | 100.0% |
| E. Wailua Iki | Upstream D1 | 640161 | FD | 0 | 42 | 0.0% | 100.0% |
| E. Wailua Iki | Downstream D1 | 640165 | barrier | 0 | 42 | 0.0% | 100.0% |
| Kopiliʻula | Upstream D1 | 640171 | FD | 0 | 42 | 0.0% | 100.0% |
| Kopiliʻula | Downstream D1 | 640175 | barrier | 0 | 42 | 0.0% | 100.0% |
| Waiohue | Upstream D1 | 640181 | FD | 0 | 42 | 0.0% | 100.0% |
| Waiohue | Downstream D1 | 640185 | barrier | 0 | 42 | 0.0% | 100.0% |
| Paakea Gulch | Upstream D1 | 640191 | FD | 0 | 42 | 0.0% | 100.0% |
| Paakea Gulch | Downstream D1 | 640195 | barrier | 0 | 42 | 0.0% | 100.0% |
| Kapāʻula Gulch | Upstream D1 | 640211 | FD | 0 | 42 | 0.0% | 100.0% |
| Kapāʻula Gulch | Downstream D1 | 640215 | barrier | 0 | 42 | 0.0% | 100.0% |
| Hanawī | Upstream D1 | 640221 | FD | 0 | 42 | 0.0% | 100.0% |
| Hanawī | Downstream D1 | 640225 | barrier | 0 | 42 | 0.0% | 100.0% |
| Hanawī | Downstream D1 | 640225 | FD | 0 | 42 | 0.0% | 100.0% |
| Makapipi | Upstream D1 | 640231 | FD | 0 | 42 | 0.0% | 100.0% |
| Makapipi | Downstream D1 | 640235 | barrier | 0 | 42 | 0.0% | 100.0% |

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