COMMISSION ON WATER RESOURCE MANAGEMENT

STATE OF HAWAII

PETITION TO AMEND INTERIM
INSTREAM FLOW STANDARDS FOR
HONOPOU, HANEHOI/PUOLUA (HUELO),
WAIKAMOI, ALO, WAHINEPEE,
PUOHOKAMOA, HAIPUAENA,
PUNALAU/KOLEA, HONOMANU,
NUAAILUA, PIINAAU, PALAUHULU,
OHIA (WAIANU), WAIOKAMILO,
KUALANI (HAMAU), WAILUANUI,
WAIKANI, WEST WAILUAIKI, EAST
WAILUAIKI, KOPILIULA, PUAKAA,
WAIOHUE, PAAKEA, WAIAAKA,
KAPAULA, HANAWI, AND MAKAPIPI
STREAMS

Case No. CCH-MA13-01

TESTIMONY OF GLENN ROBERT HIGASHI

1. I am Glenn Higashi an aquatic biologist with the Department of Land and Natural Resources (DLNR), Division of Aquatic Resources (DAR), and am testifying at the request of the Commission on Water Resources Management Hearings Officer, Dr. Larry Miike. I have worked at DAR for 29 years, with 24 years working on some aspect of freshwater systems. In addition to my work on Hawaiian streams, I coordinate multiple stream-related databases for DAR and serve as the State representative on Instream Flow Council and as a steering committee member for the Hawaii Fish Habitat Partnership.

2. DAR in collaboration with the Bishop Museum co-authored an assessment report pertaining to the quantification of the impacts of water diversions in East Maui streams on native stream animal habitat using the Hawaiian Stream Habitat Evaluation Procedure (East Maui Streams HSHEP report). The report is titled: “The Use of Hawaiian Stream Habitat Evaluation

Procedure to Provide Biological Resource Assessment in Support of Instream Flow Standards for East Maui Streams" (see Appendix A).

3. The four goals of the East Maui Streams HSHEP Report were to: 1.) explain the influence of stream diversions on the distribution and habitat availability of native stream animals; 2.) provide documentation for the HSHEP model's design, underlying data structure, and application; 3.) show changes in habitat availability for native amphidromous animals on a stream by stream basis; and, 4.) prioritize habitat and passage restoration actions among the streams of concern in East Maui.

4. East Maui Streams HSHEP Report addressed three broad areas associated with impacts on native stream animals' habitat resulting from the water diversion projects. These areas included the loss of habitat as a result of water diversion, barriers to animal movement and migration resulting from the diversion structures, and entrainment of animals in the diversion ditches.

5. The results from the HSHEP model predict that restoration of stream flows to the East Maui Streams will have varying impacts on the amount of stream animal habitat with respect to each species and all species combined into an overall native species group. Some streams would have little habitat gains while other would have substantial gains in Habitat Units. This result reflects that not all species are expected to occur in all sites within a stream, that suitable habitat varied among species within different streams, and that the extent of flow diversions was different among streams.

6. On December 15, 2009, the DAR submitted a letter (see Appendix B-December 15, 2009 letter) to Deputy Ken Kawahara with its recommendations for native aquatic biota in eight (8) streams (Honomanu, Puohokamoa, Waikamoi, Kopiliula, East Wailua Iki, West Wailua Iki, Makapipi, Hanawi). The recommendations supported restoration of native species habitat,

migratory pathways for upstream recruiting individuals and downstream drifting larvae, and overall population structure for eight native fish and macroinvertebrate species inhabiting East Maui streams and were based on several lines of evidence. First, DAR biologists and technicians spent considerable time and effort surveying habitat and animal populations in these streams. Second, the DAR compared the results of the stream surveys with estimates of expected native species occurrence by utilizing the Hawaiian Stream Habitat Evaluation Procedure (HSHEP) model, the results of which for the 19 streams in question (East Maui Streams HSHEP Report) were provided to CWRM staff on November 20, 2009. Finally, the DAR used other available information and the extensive experience of its staff in determining the final list of actions needed to support restoration of native species in these 19 streams.

7. On the minutes of the December 16, 2009 meeting, the DAR's recommendation included the total amount of habitat that could potentially be recovered in some of these streams. DAR computed ecological space for the species involved and determined the potential available habitat that was missing in the streams and could determine the amount of habitat that could be recovered from certain modifications.

8. DAR's recommendations included the modification of all existing diversions in the 8 stream to increase suitable instream habitat, minimize the entrainment of larvae, and to allow for animal passage for the recruiting post-larvae.

9. DAR staff recommendations for Hanawi Stream was all that was needed was a way to reduce entrainment in the diversion. Hanawi diversion is situated on the right bank of the stream and doesn't take all the water, so allowing a small amount of flow over the diversion such that all animals are not inevitably entrained in the ditch system. Hanawi Stream is also is a heavily gaining system.

10. DAR stated that eight (8) species of macrofauna are found in these streams and that there is variability in their climbing abilities. Of those, three (3) do not have climbing abilities and are stopped at the first major barrier; and those are *Eleotris sandwicensis, Stenogobius hawaiiensis*, and *Macrobrachium grandimanus* (prawns). Then there are five (5) species that can overcome falls and move varying distances up these streams, which includes *Lentipes concolor*, *Sicyopterus stimpsoni*, *Awaous guamensis*, *Atyoida bisulcata* (opae), and *Neritina granosa* (hihiwai). So five of the eight native species can move a considerable distance as terminal falls are no significant impediment for restoration of aquatic integrity in the stream.

11. DAR commented that it has not had direct experience in the East Maui area for whether wetted pathways would work. At the research station in Hilo, DAR staff has created their own stream and found that recruitment occurred very rapidly. Animals sense freshwater input into the ocean and move inland in response to it, particularly the animals with climbing abilities.

12. DAR's recommendation for flow restoration is to restore water in fewer streams rather than a large number of streams in order to achieve higher ecological impact. The predicted habitat loss calculated across the 19 streams was 67.3 kilometers. By addressing eight (8) of the streams, DAR believes that 68% of that habitat loss could be recovered. DAR staff is aware of the gaining and losing reach aspects and that the tiny amount of water in small pools are not adequate for certain species. DAR believes that a certain minimum depth is going to be necessary for ecosystem function integrity including depth of reaches.

13. DAR stated that there are two components for streamflow: 1) the base flow which essentially means the ground water contribution that's always coming in; 2) the effects from rainfall which augment base flow, comprising total flow in the stream. As a result of seasonal rainfall pattern, there is lower total flow during the summer than in the winter. The native

animals that occupied the streams have evolved around that annual variation in flow. It is less pronounced in certain systems because systems like Hanawi are highly spring fed, thus the base flow is very high. Hanawi probably has less of a total variation over the year than most of the other streams under discussion. While Hanawi has low annual variation in flow due to Big Spring input, other streams do have pronounced seasonal variations.

14. DAR stated that animals may hold over in stream sections that still flow or in pools during periods when there is not complete connectivity. In other words, 100% complete animal connectivity is not required to still have some biological viability. More water in the stream is better for animals, but if certain sections dry up for a period, it's not necessarily fatal to the biota as a whole. If streamflow could be fully restored the maximum benefit would be realized. But even if it could be mitigated for portions of the year, with streamflow more than what it is now (because now connectivity only occurs during high rainfall events) that would provide positive effects.

15. DAR stated that flow improvement over the current situation would likely increase recruitment. The tools are available to be able to assess what is gained, rather than just guessing. The HSHEP model can calculate habitat units gained by the various management actions and provide quantitative outputs that can then be tested by ground-truthing. The exact extent of which the stream was improved could then be documented by the field research.

16. DAR worked out the total predicted habitat loss in this system based upon an analysis of eight (8) species of macrofauna and their habitat characteristics. Using GIS, DAR analyzed these species using a 10-meter grid and determined the aggregate kilometers of habitat in any given stream that the species occupy, don't occupy, or could potentially occupy. When DAR looked at this in total, across these eight species and for the streams under consideration, there is a total

habitat loss of 67.3 kilometers of habitat. That doesn’t mean 67 linear kilometers of stream, but rather 67 km of Habitat Units for all eight species among all streams. DAR’s recommendation stated that with improvements to a few strategic catchments, the Commission could mitigate 68% of that habitat loss.

17. DAR commented as for water volume, that some flow restoration is going to create some improvements even if it’s a seasonal issue for the biota, and that DAR could go back to the streams and measure the results. DAR added that it would vary on a species-by-species basis as some species may require more water for passage.

18. DAR stated that there are a wide variety of diversion structures on the EMI system, thus a simple solution would be difficult as each diversion presents a different challenge. However, there’s one generalization is that many diversions utilize a grate that extends across the width of the streambed. As the water comes down, the total flow goes into the grate and thus no water passes over the diversion, so that all the water is taken in and then moved off laterally. Those structures, in particular, are the types of structures that result in nearly 100% entrainment. So, even if the organisms are recruited, the benefits would not be realized because they would be lost. What is needed is some way to partially bypass the grate so that a certain amount of water could flow over a portion of it to provide some sort of fish and animal passage corridor. The passage would not need to be that large so that even they could bypass a certain proportion of the diversion, and some proportion of species were able to make it back downstream, then it’s better than the situation today.

19. Of the 27 streams addressed by CWRM, the DAR East Maui Streams HSHEP report only addressed the second group of streams in East Maui (19 streams as described by CWRM, 16 distinct stream and their tributaries in the report) where instream flow to biotic resources was

considered and was not performed for the first group of streams (8 streams) where instream flow for taro cultivation was the primary concern. Modeling runs included all 27 streams, but analysis and reporting of impact to native species Habitat Units were limited to the second group of 19 streams as directed by CWRM.

20. DAR's recommended streams were based on the list of streams addressed and provided by CWRM staff.

21. On the minutes of the May 25, 2010 meeting, DAR supported the following positions regarding restoration efforts in East Maui Streams. DAR provided the minimum flow needs for stream biota in a seasonal approach as requested from the December 2009 Commission meeting (see Appendix C-April 1, 2010 and Appendix D-May 17, 2010 letters). DAR recommended that in the wet season, 64-percent of the base flow is needed in the stream to support minimum habitat in the wet season. In the dry season, 20-percent of the base flow in the stream is needed to support minimum connectivity for upstream and downstream migration of the stream animals. Some discrepancies between flow recommendation developed by DAR and CWRM were mostly resulting from locational differences and in the use of estimated flow. DAR based its estimates in the middle of the lower reaches of the stream rather than the upper reaches, which is where CWRM staff would be monitoring.

22. DAR staff stated that the 64-percent of the median base flow (H_{min}) was expected to provide enough water for the stream animals to complete a number of biological functions including feeding, growth, courtship and reproduction. The other flow rate number (C_{min}) is the dry season connectivity flow that would not be sufficient water for all the needed biological functions to occur. The C_{min} flow rate was to provide enough water in the stream where the animals can move between pools or to move to other more suitable areas.

23. DAR staff stated that the ʻoʻopu, ʻōpae, and hīhīwai all share a life cycle similar to that of salmon and eels. This kind of lifestyle is characteristic of all Pacific islands. Generally, during the spring time, babies anywhere from a quarter of an inch long migrate en masse into the stream and then make their way upstream. These babies need some water to move into that habitat. Therefore, in streams that lack connectivity flow or with low flows, the animals would be unable to reproduce, to feed, or be healthy. During the summertime with longer daylight hours, the animals are very active in reproduction and the eggs are hatched upstream. Usually during the autumn, the first flow occurs when the eggs are very small from about an eighth inch in diameter and they move downstream. This is the complete life cycle, in which the animals live about three months in the ocean and nine months in the streams. Staff summarized that there are two ways of stream animal migration - incoming in the spring time and the outgoing as eggs.

24. DAR felt nine streams would be the “biggest bang for the buck” for habitat restoration. DAR is very adamant about the H_{min} flow rates, which should be 64-percent of natural median base flow and is necessary to provide enough water in the stream for the animals. DAR added that it is more desirable to restore flow to H_{min} flow rates in fewer streams, rather than restoring even lower flows to more streams. Thus, the minimum flow of 64-percent of natural median base flow is very important.

25. DAR staff understood that there are multiple uses for the valuable water resource. Therefore, they would prefer that one or two streams be restored to the H_{min} (rather than more streams at lower flows) because these are the streams where the babies are going to come from and with time the propagules will spread along the coastal areas and come back in other streams as well. DAR would support having interim IFS in a few good streams.

26. DAR has recently completed as monitoring study on the East Maui Streams entitled: "Monitoring Changes in Habitat, Biota, and Connectivity Resulting From Water Returns in the East Maui Streams of East Wailua Iki, West Wailua Iki, and Waiohue." The study addressed instream flow restoration for the East and West Wailua Iki and Waiohue Streams. The three East Maui streams were monitored for habitat, connectivity, and biota changes as a result of seasonal instream flow releases on a quarterly basis for a period of 4 years. (See Appendix E for DAR study entitled: "Monitoring Changes in Habitat, Biota, and Connectivity Resulting From Water Returns in the East Maui Streams of East Wailua Iki, West Wailua Iki, and Waiohue".)

27. The monitoring results were not definitive, but suggest that winter flow releases did make a positive improvement to instream habitat in the upper stations and that the summer releases showed little difference in habitat, connectivity and biota.

28. Although the lower sites on all three streams monitored had relatively healthy animal populations, recovery of native stream animal populations at the upper sites below the diversions was not observed. This may be a result of poor conditions during summer flow releases or insufficient time for the animals to repopulate the areas.

29. In general, the results showed weak or no relationship between flow releases and habitat, connectivity, or biota. It is likely the study period was too short to document changes given natural variability in rainfall and streamflow, and recruitment and dispersal of stream animals.

30. The study was important as it directly tested the seasonal flow concept by observing changes over time in three different flow controlled streams. These results can be used in an adaptive management framework to help determine appropriate flow rates for Hawaiian streams.

31. Based on the results of the monitoring study, the application of very low summer flows is not supported as a suitable instream flow approach for restoration of native stream animals. The

application of the higher flows appeared to have positive benefits to the instream habitat and will likely result in positive stream animal benefits over time.

32. DAR recommendation that there should be a constant annual flow (equal to the winter flow standard) year round to make a difference in habitat, connectivity and biota. Additionally, monitoring the instream flow release needs to be performed over for a longer period of time to document whether or not improvement to the animal population occurs.

Appendix

To the Testimony of Glenn Higashi

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

B - December 15, 2009 letter.pdf

C - April 1, 2010 letter.pdf

D - May 17, 2010 letter.pdf

E - Monitoring Changes in Habitat, Biota, and Connectivity Resulting From Water Returns in the East Maui Streams of East Wailua Iki, West Wailua Iki, and Waiohue.pdf

GLENN R. HIGASHI

Aquatic Biologist
Department of Land and Natural Resources
Division of Aquatic Resources
1151 Punchbowl Street Suite 330, Honolulu, HI 96813
808-587-0112
glenn.r.higashi@hawaii.gov
http://dlnr.hawaii.gov/dar/

PROFESSIONAL PROFILE

- Over 29 years of experience as an aquatic biologist in recreational fisheries development and management; stream ecosystem biology, management, and restoration; and data collection and management.
- Developed coding for stream locations for the Division of Aquatic Resources Aquatic Resources' Database and assisted in its design, development and management.
- Assisted in the design, development and testing of point quadrat, rapid bioassessment, and monitoring methodologies for stream surveys.
- Conducted point quadrat, rapid bioassessment and monitoring surveys in Hawaiian Streams statewide on all islands.
- Co-authored the "Atlas of Hawaiian Watershed and Their Aquatic Resources" to distribute stream biota and watershed information to the general public.
- Assisted in the development of the Hawaiian Stream Habitat Evaluation Procedures (HSHEP) model to evaluate habitat units of native species.
- Conducted literature searches, collected biological data and specimens on fishery resources on research and commercial ship cruises to the Northwest Hawaiian Islands using and fabricating different gear types, and prepared reports on commercial and research cruises.

EDUCATION

Chaminade University—Honolulu, HI 1968-1970
University of Hawaii—Honolulu, HI 1970-1974
B.A. Zoology, May, 1974

PROFESSIONAL EXPERIENCE

1979-Present	Department of Land and Natural Resources, Division of Aquatic Resources—Honolulu, HI, Aquatic Biologist
2006-Present	Project leader for Dingell-Johnson Project F-17-R, Study III, Job No. 4; Statewide Marine Research & Surveys, Marine Surveys and Inventories, Aquatic Resources Database.

2006-2012	Project leader for Dingell-Johnson Project F-14-R, Study VII, Job No. 8; Freshwater Fisheries Research & Surveys, Native Freshwater Species and Ecosystem Studies, Stream/Estuarine Fisheries.
2006-2012	Project leader for Dingell-Johnson Project F-15-T, Study I, Job No. 1; Statewide Freshwater Fisheries Technical Guidance, Environmental Impact Assessment.
1980-1990	Project leader for Dingell-Johnson Project F-17-R, Marine Fisheries Development, Statewide Fish Aggregating Device System.
1977-1979	NOAA, National Marine Fisheries Service—Honolulu, HI., Fisheries Technician

PROFESSIONAL AFFILIATIONS

2013-Present Instream Flow Council Representative for Hawaii
2011- Present Hawaii Fish Habitat Partnership Steering Committee Member
2005-2007 Conservation Steering Committee member for Waimea Valley Audubon Center

PUBLICATIONS AND PRESENTATIONS

Books

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

Parham, J.E., **G. R. Higashi**, E. K. Lapp, D. G. K. Kuamo'o, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick 2008. *Atlas of Hawaiian Watersheds & Their Aquatic Resources: Island of Kauai*. Bishop Museum & Division of Aquatic Resources. Honolulu, HI. 614 p.

Parham, J.E., **G. R. Higashi**, E. K. Lapp, D. G. K. Kuamo'o, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick 2008. *Atlas of Hawaiian Watersheds & Their Aquatic Resources: Island of Oahu*. Bishop Museum & Division of Aquatic Resources. Honolulu, HI. 672 p.

Parham, J.E., **G. R. Higashi**, E. K. Lapp, D. G. K. Kuamo'o, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick 2008. *Atlas of Hawaiian Watersheds & Their Aquatic Resource:. Island of Maui*. Bishop Museum & Division of Aquatic Resources. Honolulu, HI. 866 p.

Parham, J.E., **G. R. Higashi**, E. K. Lapp, D. G. K. Kuamo'o, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick 2008. *Atlas of Hawaiian Watersheds &*

Their Aquatic Resources. Island of Molokai: Bishop Museum & Division of Aquatic Resources. Honolulu, HI. 420 p.

Parham, J.E., **G. R. Higashi**, E. K. Lapp, D. G. K. Kuamo'o, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick 2008. *Atlas of Hawaiian Watersheds & Their Aquatic Resources: Island of Hawaii*. Bishop Museum & Division of Aquatic Resources. Honolulu, HI. 1262 p. (3 volumes).

Peer-Reviewed Publications

Kuamo'o, D. G. K., **G. R. Higashi** & J. E. Parham. 2007. *Structure of the Division of Aquatic Resources Survey Database and use with a Geographic Information System.* In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis & J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3: 315-322.

Higashi, G. R. & R. T. Nishimoto. 2007. The point quadrat method: a rapid bioassessment of Hawaiian streams. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis & J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3: 305-314.

Higashi, G. R. & M. N. Yamamoto. 1993. *Rediscovery of "extinct" Lentipes concolor* (Pisces: Gobiidae) *on the island of Oahu, Hawaii*. Pacific Science 47(2): 115-117.

Technical Reports

Parham J.E. and **G.R. Higashi**, 2012. *Tier 2 Barrier Survey Methodology and Forms: Assessing Restrictions to Passage of Amphidromous Species in Hawaiian Streams – V1.2*. Division of Aquatic Resources and US Fish and Wildlife Service. 38 p.

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

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo'o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Kolea Stream, Maui, Hawai'i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 36 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo'o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Waikamoi Stream, Maui, Hawai'i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 44 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Puohokamoa Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 32 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Punalau Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 32 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Honomanu Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 64 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Nua’ailua Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 56 p.

Higashi, G.R,, J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on ‘Ohi’a Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 38 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on West Wailua Iki Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 57 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on East Wailua Iki Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Kopili’ula Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Waiohue Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Paakea Gulch, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Kapa’ula Gulch, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 34 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Hanawi Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 46 p.

Higashi, G.R., J.E. Parham, E.K. Lapp, S. Hau, D.G.K. Kuamo’o, L.K. Nishiura, T.T. Shindo, T.S. Sakihara, T.E. Shimoda, R.T. Nishimoto, and D.A. Polhemus. 2009. *Report on Makapipi Stream, Maui, Hawai’i*. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

Higashi, G.R., J.E. Parham, S. Hau, R.T. Nishimoto, D.A. Polhemus, E.K. Lapp, L.K. Nishiura, T.T. Shindo, and T.S. Sakihara. 2008. *Report on Honopou Stream, Maui*. For the Commission on Water Resources Management. DLNR, Honolulu, HI. 50p.

Higashi, G.R., J.E. Parham, S. Hau, R.T. Nishimoto, D.A. Polhemus, E.K. Lapp, L.K. Nishiura, T.T. Shindo, and T.S. Sakihara. 2008. *Report on Hanehoi Stream, Maui*. For the Commission on Water Resources Management. DLNR, Honolulu, HI. 46p.

Higashi, G.R., J.E. Parham, S. Hau, R.T. Nishimoto, D.A. Polhemus, E.K. Lapp, L.K. Nishiura, T.T. Shindo, and T.S. Sakihara. 2008. *Report on Piinaau Stream, Maui*. For the Commission on Water Resources Management. DLNR, Honolulu, HI. 43p.

Higashi, G.R., J.E. Parham, S. Hau, R.T. Nishimoto, D.A. Polhemus, E.K. Lapp, L.K. Nishiura, T.T. Shindo, and T.S. Sakihara. 2008. *Report on Wailuanui Stream, Maui*. For the Commission on Water Resources Management. DLNR, Honolulu, HI. 34p.

Higashi, G.R., J.E. Parham, S. Hau, R.T. Nishimoto, D.A. Polhemus, E.K. Lapp, L.K. Nishiura, T.T. Shindo, and T.S. Sakihara. 2008. *Report on Waiokamilo Stream, Maui*. For the Commission on Water Resources Management. DLNR, Honolulu, HI. 32p.

King, C., E.K. Lapp, J.E. Parham, **G.R. Higashi**, S. Hau and D.G.K Kuamo’o. 2008. *Survey report on Waihe’e Stream, Maui, Hawai'i*. Division of Aquatic Resources, DLNR, State of Hawaii.

King, C., E.K. Lapp, J.E. Parham, **G.R. Higashi**, S. Hau and D.G.K Kuamo'o. 2008. *Survey report on Pi'inaau Stream, Maui, Hawai'i*. Division of Aquatic Resources, DLNR, State of Hawaii.

King, C., E.K. Lapp, J.E. Parham, **G.R. Higashi**, S. Hau and D.G.K Kuamo'o. 2008. *Survey report on Waiehu Stream, Maui, Hawai'i*. Division of Aquatic Resources, DLNR, State of Hawaii.

King, C., E.K. Lapp, J.E. Parham, **G.R. Higashi**, S. Hau and D.G.K Kuamo'o. 2008. *Survey report on Honopou Stream, Maui, Hawai'i*. Division of Aquatic Resources, DLNR, State of Hawaii.

King, C., E.K. Lapp, J.E. Parham, **G.R. Higashi**, S. Hau and D.G.K Kuamo'o. 2008. *Survey report on Waiokamilo Stream, Maui, Hawai'i*. Division of Aquatic Resources, DLNR, State of Hawaii.

Databases

Parham, J.E., D.G.K Kuamo'o, and **G.R. Higashi**. 2002-2010. Hawai'i Division of Aquatic Resources Surveys Database. A database to store historical and current fisheries surveys in nearshore, esturine, and stream environments. Versions 1-4. Hawai'i Division of Aquatic Resources.

Presentations

Higashi, Glenn and Eko Lapp. *"What Do We Know and How Is It Related? Organizing Data Based on a Ridge-to-Reef Concept"* 2014 Hawaii Conservation Conference. Navigating Change in the Pacific Islands. July 15-17, 2014.Hawaii Convention Center, Honolulu,HI. In Symposium: Adapting to New Challenges-Innovative Science and Management Techniques for Emerging Issues in Marine and Coastal Ecosystems, Conference Presentation.

Parham, J.E. and **G.R. Higashi**. 2012. Integrated Databases to Support "Ridge-to-Reef" Fisheries Management in Hawaii. 142nd Annual Meeting of the American Fisheries Society, Minneapolis, MN. (Invited speaker)

Parham, J.E., **G.R. Higashi**, E.K. Lapp, D.G.K. Kuamo'o, R.N. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2009. Synthesizing results from current and historical stream surveys in Hawaii to determine fish distribution and habitat use at multiple spatial scales. National Fish Habitat Mapping Symposium. Annual Meeting of the American Fisheries Society, Nashville, TN. (Invited speaker)

Parham, J.E., **G.R. Higashi**, E.K. Lapp, D.G.K. Kuamo'o, R.N. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008. Atlas of Hawaiian Watersheds and Their Aquatic Resources: An important tool to aid in statewide stream and watershed management. Workshop on the Ecology, Restoration, and Management of Hawaii Stream and Riparian Systems. Kaneohe, HI. (Invited speaker)

Parham, J.E., **G.R. Higashi**, E.K. Lapp, D.G.K. Kuamo'o, R.N. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008. Atlas of Hawaiian Watersheds and Their Aquatic Resources – an important tool to aid in statewide watershed management. Workshop on the Ecology, Restoration, and Management of Hawaii Stream and Riparian Systems. Kaneohe, HI. (Invited speaker)

Parham, J.E., **G.R. Higashi**, E.K. Lapp, D.G.K. Kuamo'o, R.N. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008. Atlas of Hawaiian Stream Species – describing habitat and distribution of stream animals statewide. Workshop on the Ecology, Restoration, and Management of Hawaii Stream and Riparian Systems. Kaneohe, HI. (Invited speaker)

Parham, J.E., **G.R. Higashi**, E.K. Lapp, D.G.K. Kuamo'o, R.N. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008. Atlas of Hawaiian Watersheds and Their Aquatic Resources – an important tool to aid in statewide watershed management. Hawaii Conservation Conference. Honolulu, HI. (Invited speaker)

Parham, J.E., **G.R. Higashi**, E.K. Lapp, D.G.K. Kuamo'o, R.N. Nishimoto, S. Hau, D.A. Polhemus, J.M. Fitzsimons, and W.S. Devick. 2008. Atlas of Hawaiian Stream Species – describing habitat and distribution of stream animals statewide. Hawaii Conservation Conference. Honolulu, HI. (Invited speaker)

Higashi, G. R. 2007. Kahana Stream Surveys. Kahana Neighborhood Community Meeting, Kahana, HI. Presentation. (Invited speaker)

Higashi, G.R., D.G.K. Kuamo'o, and J.E. Parham. 2006. Division of Aquatic Resources' Aquatics Surveys Database: Use and Applications. State of Hawaii Commission on Water Resources. Honolulu, HI. (Invited speaker)

Higashi, G. R. & R. T. Nishimoto. 2005. The point quadrat method: a rapid bioassessment of Hawaiian streams. Symposium on Hawaiian Streams and Estuaries. Hilo, HI. (Invited speaker)

*Kuamo'o, D.G.K., **G.R. Higashi**, and J.E. Parham. 2005. Structure of the Division of Aquatic Resources Surveys Database and Use with a Geographic Information System. Symposium on Hawaiian Streams and Estuaries. Hilo, HI. (Invited speaker)

Appendix A

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

James E. Parham, Ph.D.[1]

Glenn R. Higashi[2]

Robert T. Nishimoto, Ph.D.[2]

Skippy Hau[2]

Darrell G.K. Kuamo'o[2]

Lance K. Nishiura[2]

Troy S. Sakihara[2]

Troy E. Shimoda[2]

Timothy T. Shindo[2]

[1]Bishop Museum
[2]Division of Aquatic Resources

November 20, 2009

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.

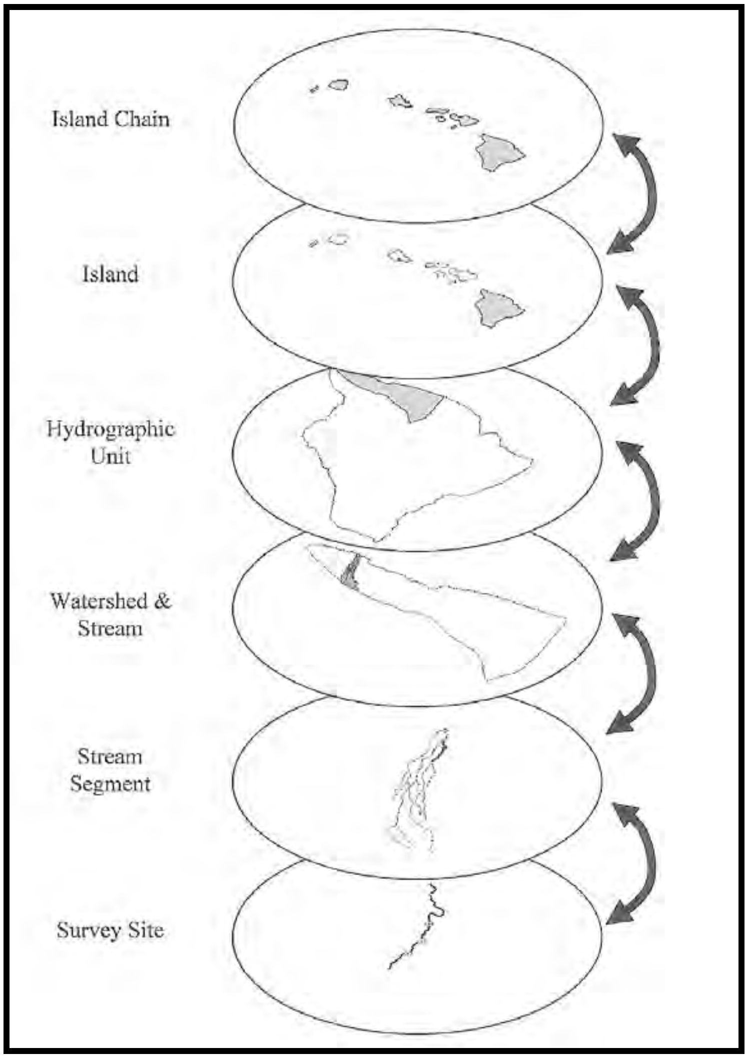


Figure 1. Spatially nested hierarchy of the DAR Aquatic Surveys Database and predictive levels within the HSHEP model.

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.

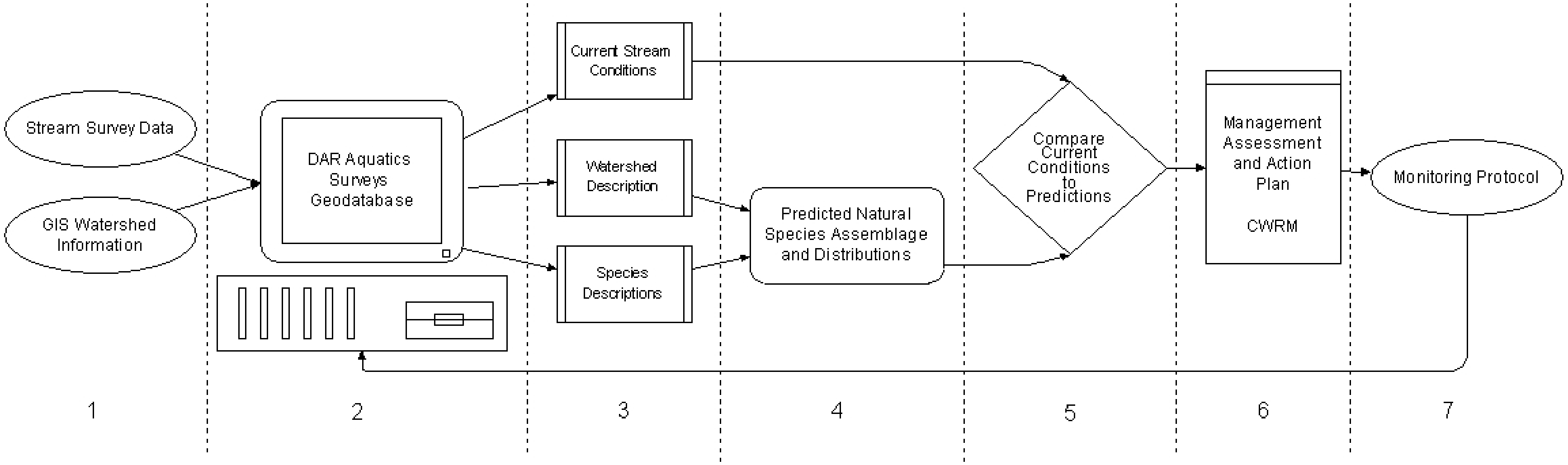


Figure 2. Stream Management Process Flow Chart. The flow chart outlines the steps and products needed to provide objective stream management assessments and monitoring efforts to support Instream Flow decision by the Commission on Water Resources Management (CWRM). Step 1 is the collection of information 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.

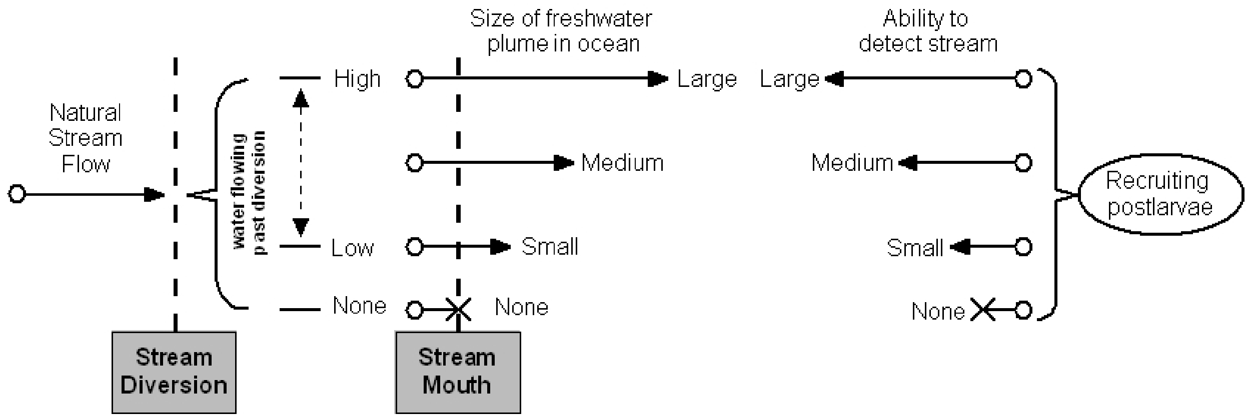


Figure 4. A conceptual model describing the role of streamflow into the ocean in attracting recruiting postlarval animals to the stream. Stream diversions decrease the size of the freshwater plume and therefore make it harder for recruiting animals to detect the freshwater from their offshore larval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

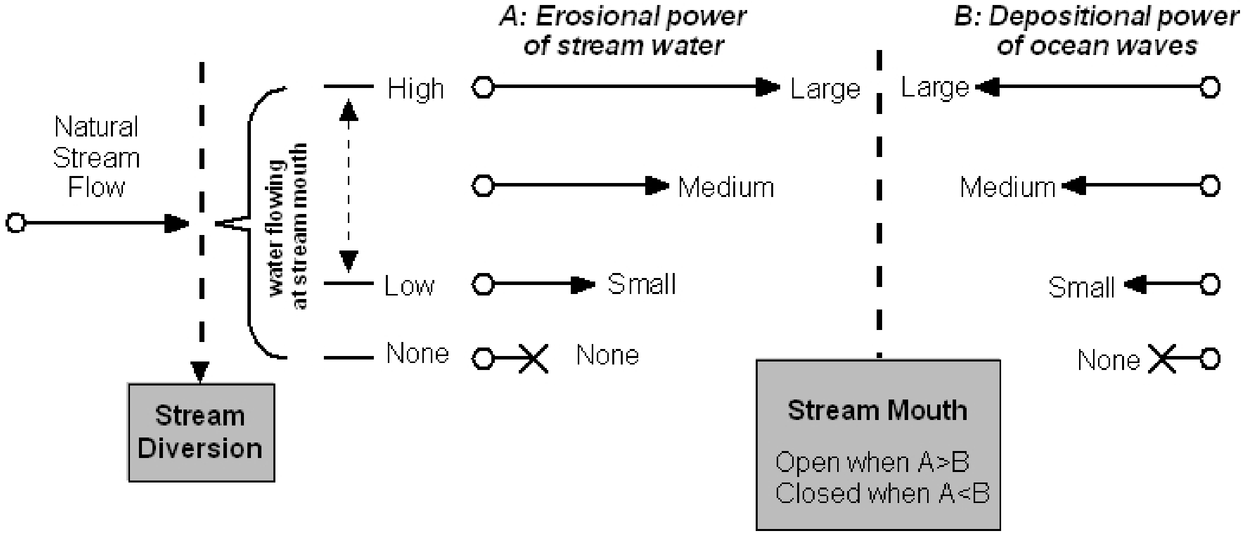


Figure 6. Conceptual model of the balance between stream power and ocean power in controlling the presence or absence of a berm at the stream mouth. When the stream mouth is open, recruiting stream animals can easily move upstream, while when a stream is closed by a berm, recruitment into the stream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

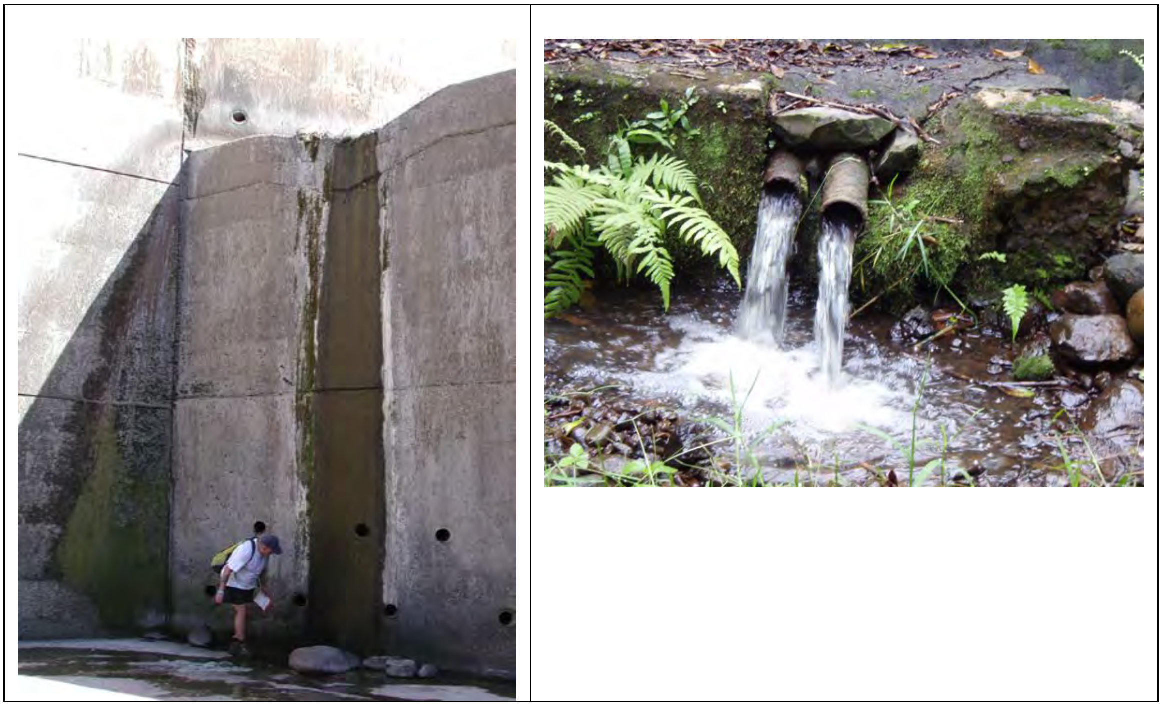


Figure 8. Vertical drop as a barrier on ʻĪao Stream, Maui (left) and a pipe providing for water flow downstream over a diversion on Hanehoi Stream, Maui. While not actual stream diversions, the images show potential obstacles that animals migrating upstream may encounter. Notice the extent of the drop 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.

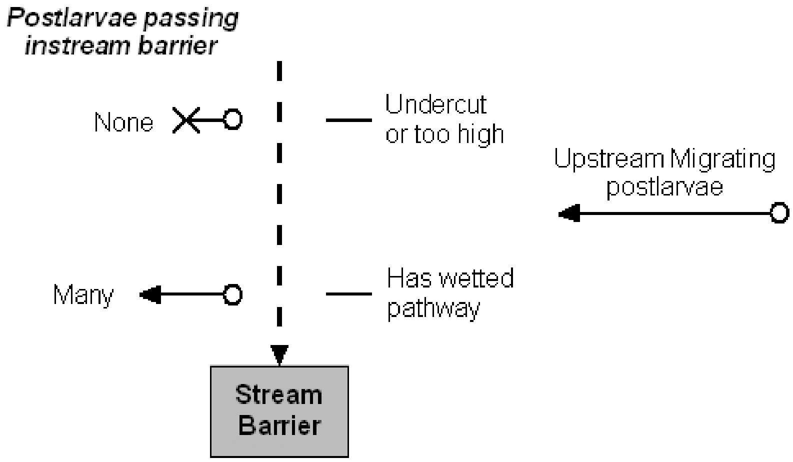


Figure 10. Conceptual model of the physical blockage of upstream migration instream structures.

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 Kopili‘ula 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.

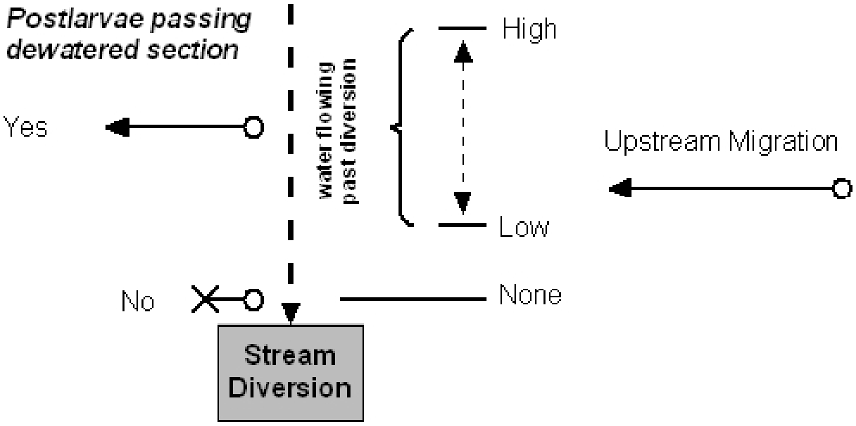


Figure 12. Conceptual model showing the probability of upstream passage by postlarvae of native amphidromous stream animals. Upstream movement would be possible when water is flowing past the diversion and provides a continuous pathway through previously dewatered stream section.

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.

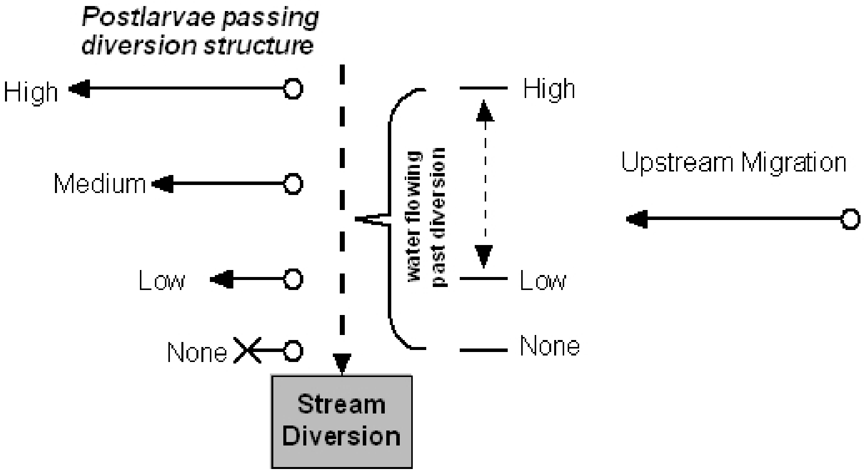


Figure 14. Conceptual model of the extent of upstream passage by postlarvae of native amphidromous stream animals. Entrainment of postlarvae would be a function of the proportion of amount of water passing the diversion and the amount flowing into the diversion.

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.

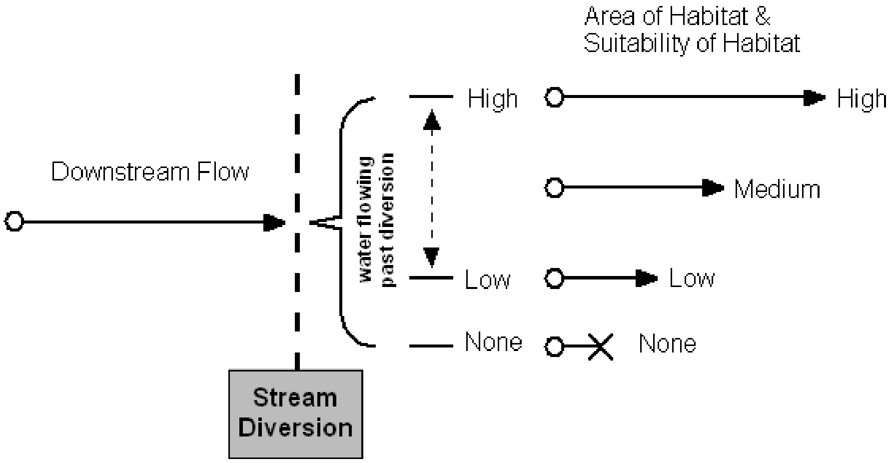


Figure 16. – Conceptual model of the influence of stream diversion on instream habitat.
From a management perspective, instream habitat needs to provide adequate conditions for the animals to survive during drought conditions, provide cover to avoid predation and high flow events, supply enough food 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.

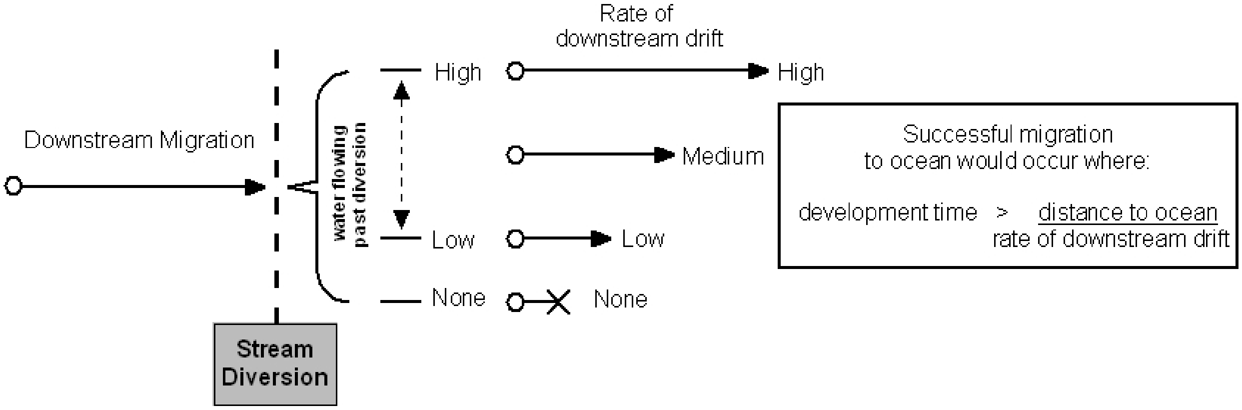


Figure 18. Conceptual model of the influence of stream diversion on travel time and ultimately the success of downstream drifting embryos of native amphidromous stream animals in reaching the ocean within a suitable development period. Successful downstream migration would be a function of rate of downstream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

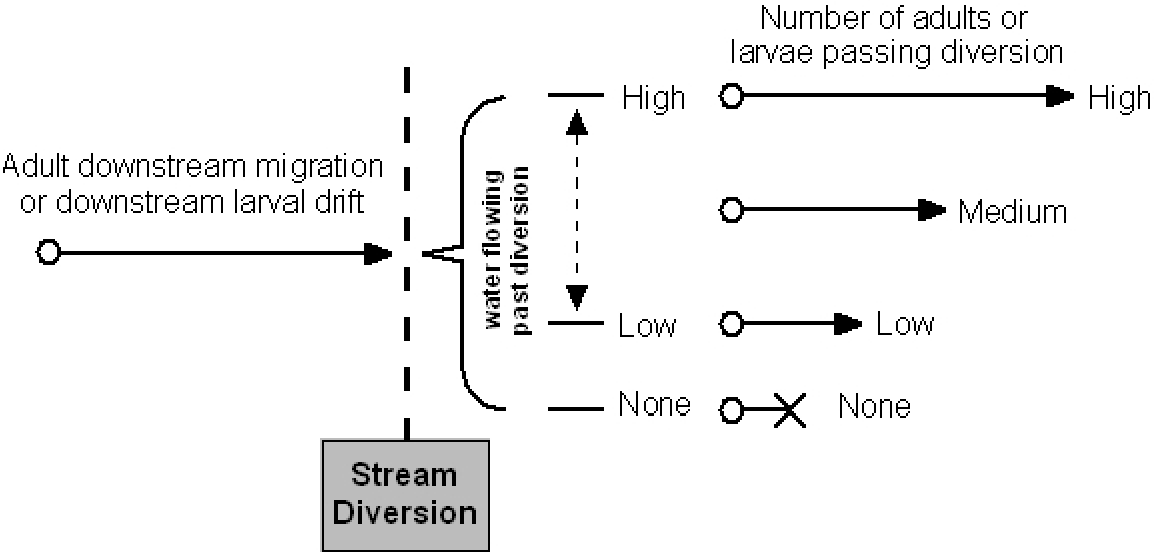


Figure 20. Conceptual model of the extent of diversion passage by downstream drifting larvae of native amphidromous stream animals. Entrainment of larvae would be a function of the proportion of amount of water passing over the diversion to the amount flowing into the diversion.

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	Watershed ID
1	Kōlea	64003
2	Waikamoi	64004
3	Puohokamoa	64006
4	Haipua‘ena	64007
5	Punalau	64008
6	Honomanū	64009
7	Nua‘ailua	64010
8	‘Ōhi‘a	64012
9	W. Wailua Iki	64015
10	E. Wailua Iki	64016
11	Kopili‘ula	64017
12	Waiohue	64018
13	Paakea	64019
14	Kapā‘ula	64021
15	Hanawī	64022
16	Makapipi	64023

An additional stream, Waia‘aka 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 Waia‘aka 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 using the HSHEP requested by CWRM.

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

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

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.

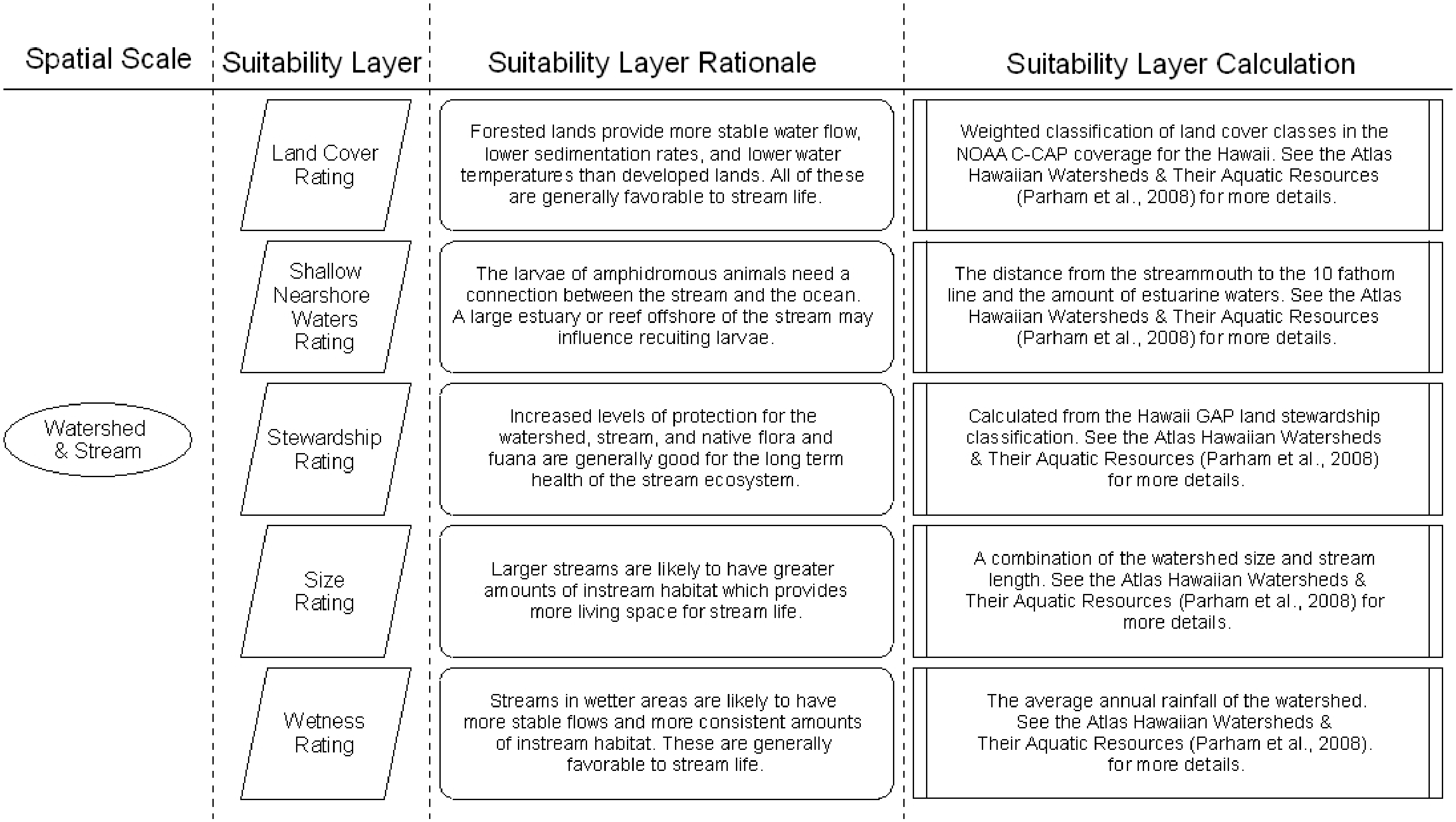
The HSHEP is based on a nested spatial hierarchy (Figure 1). Depending on the question being modeled, various levels of the hierarchy are used. In this report, the spatial levels for watershed, stream segment, and site will be used. The spatial levels of island chain, island, and region are not needed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

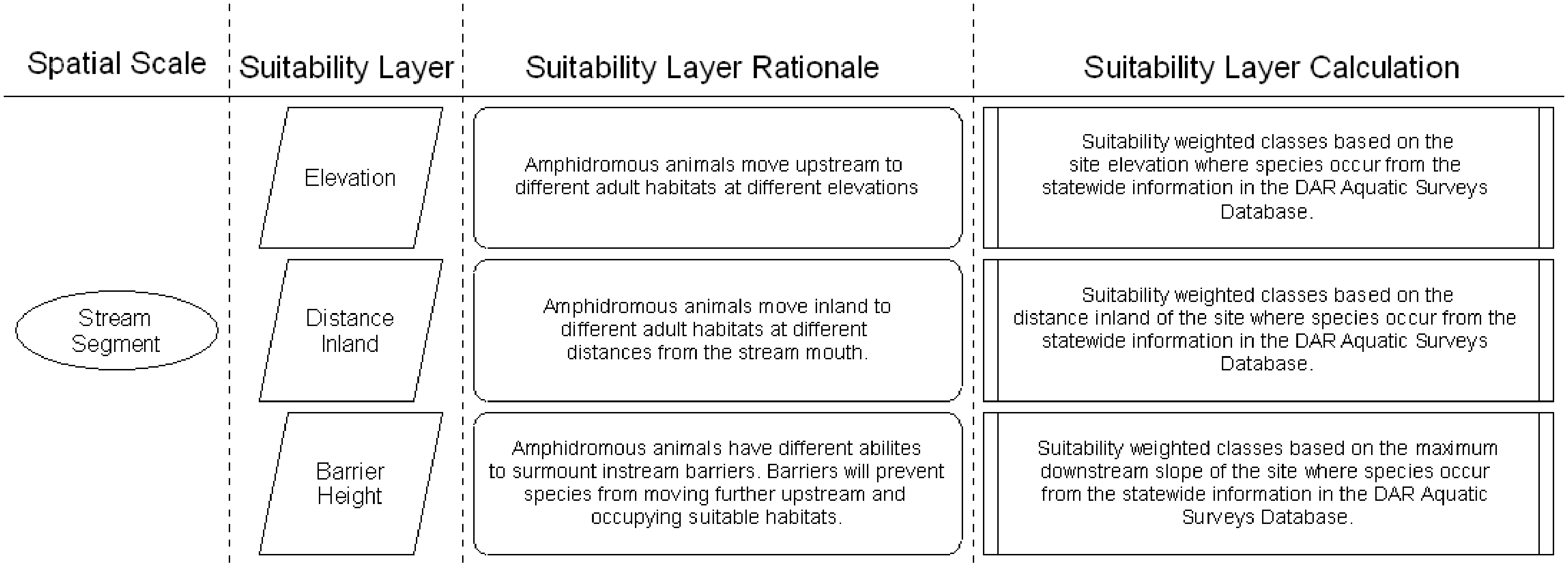
At the site level, more specific habitat characteristics are important. Water depth, temperature, velocities, bottom composition, and habitat type are used to describe suitable habitat for a species at this spatial scale (Figure 23). For the HSHEP analysis used for the East Maui streams reported here, 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.



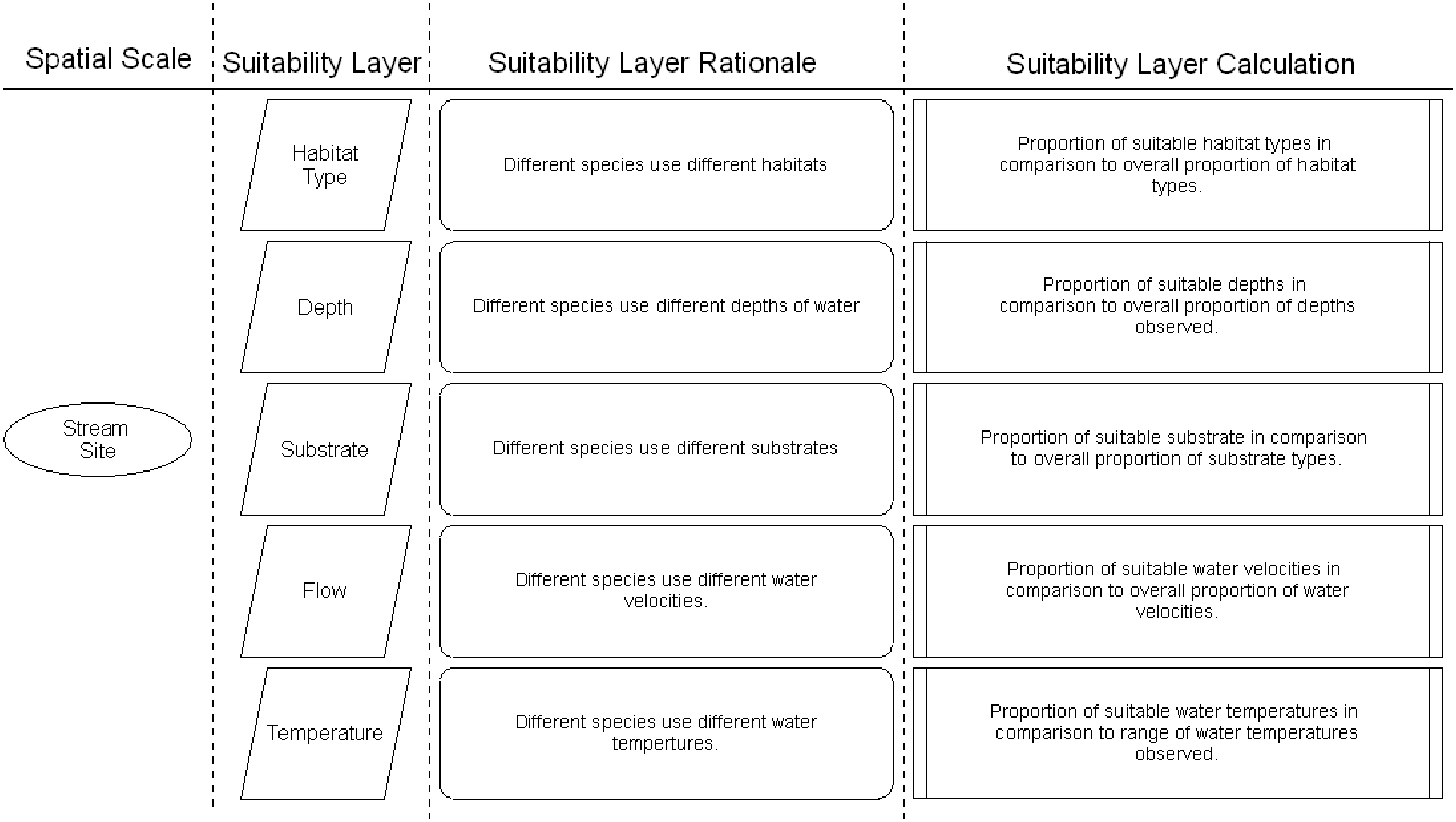
Spatial Scale	Suitability Layer	Suitability Layer Rationale	Suitability Layer Calculation
Watershed & Stream	Land Cover Rating	Forested lands provide more stable water flow, lower sedimentation rates, and lower water temperatures than developed lands. All of these are generally favorable to stream life.	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.



Spatial Scale	Suitability Layer	Suitability Layer Rationale	Suitability Layer Calculation
Stream Site	Habitat Type	Different species use different habitats	Proportion of suitable habitat types in comparison to overall proportion of habitat types.
	Depth	Different species use different depths of water	Proportion of suitable depths in comparison to overall proportion of depths observed.
	Substrate	Different species use different substrates	Proportion of suitable substrate in comparison to overall proportion of substrate types.
	Flow	Different species use different water velocities.	Proportion of suitable water velocities in comparison to overall proportion of water velocities.
	Temperature	Different species use different water tempertures.	Proportion of suitable water temperatures in comparison to range of water temperatures observed.

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

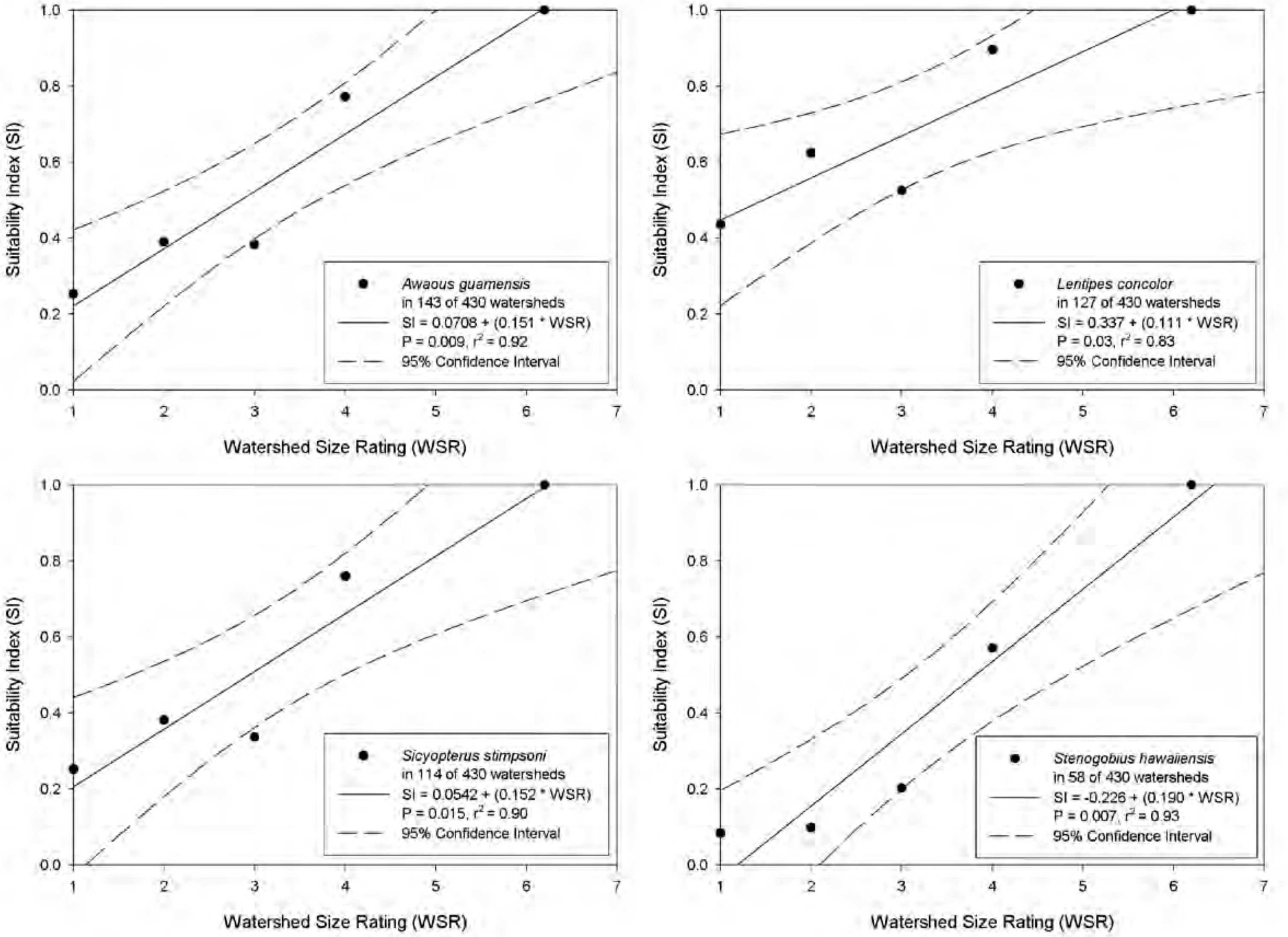


Figure 24. Suitability Indices for Watershed Size Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

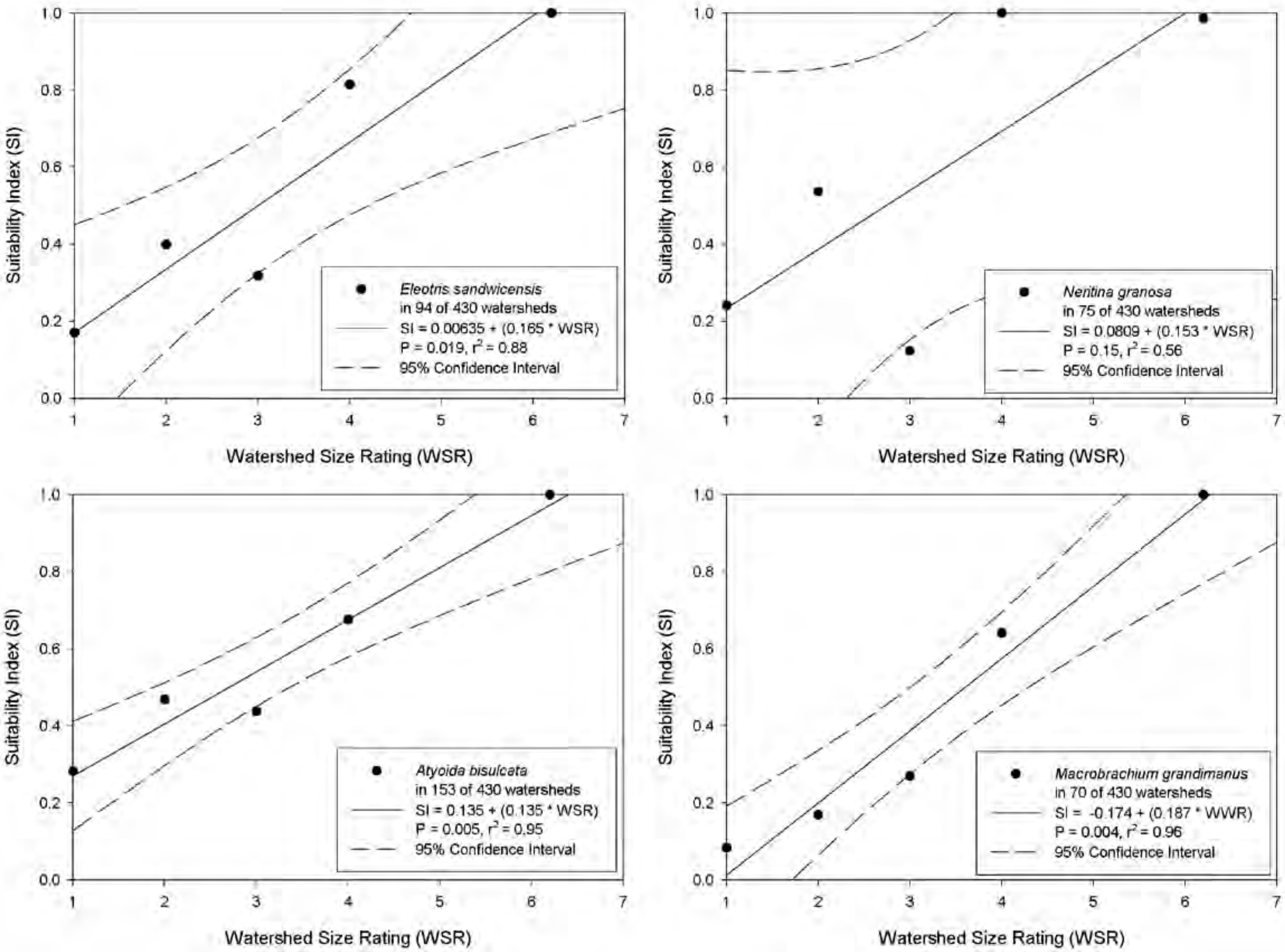


Figure 25. Suitability Indices for Watershed Size Rating for *Eleotris sandwicensis*, *Neritina granosa*, *Atyoida bisulcata*, and *Macrobrachium grandimanus.*

Watershed Wetness Rating

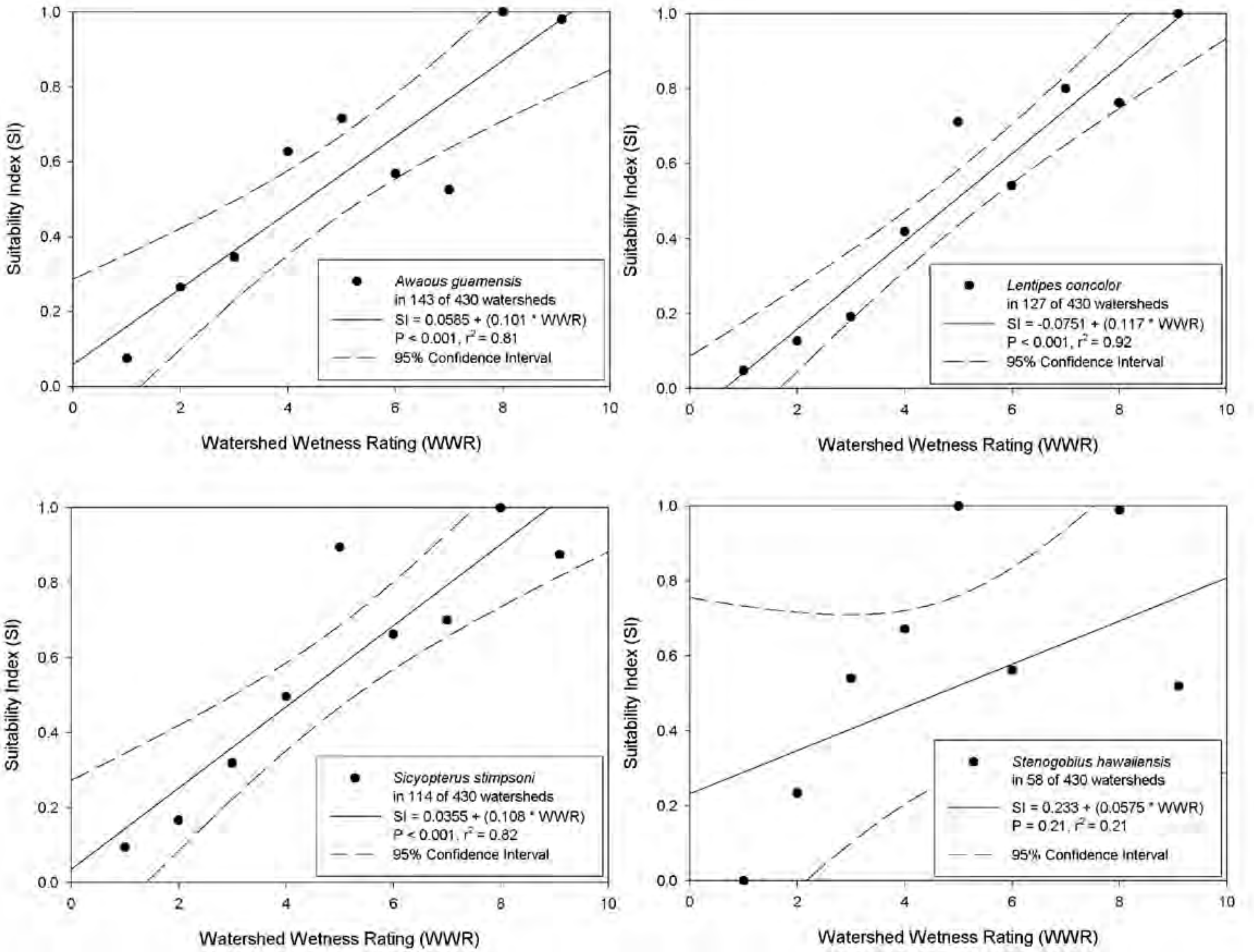


Figure 26. Suitability Indices for Watershed Wetness Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

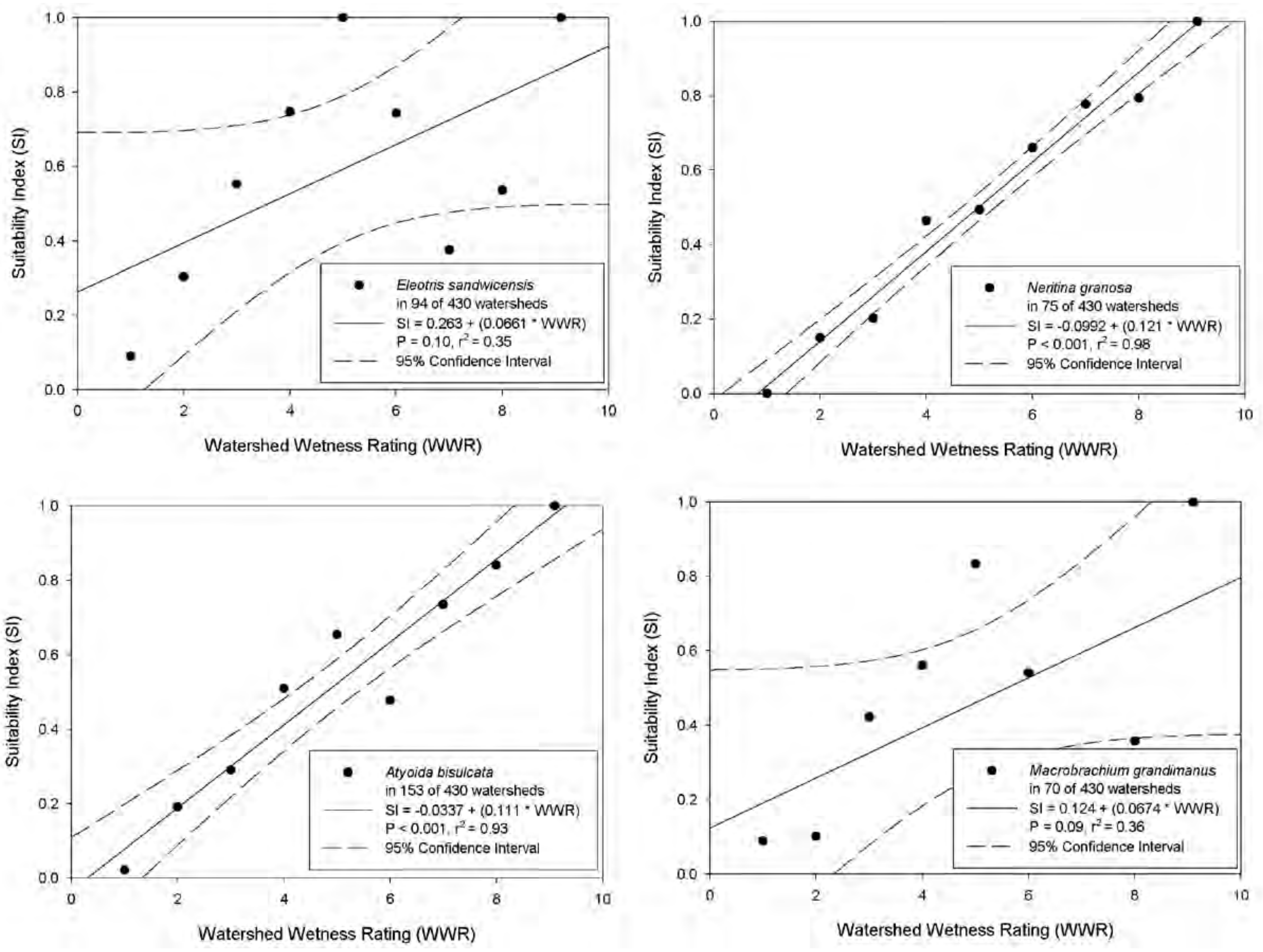


Figure 27. Suitability Indices for Watershed Wetness Rating for *Eleotris sandwicensis*, *Neritina granosa*, *Atyoida bisulcata*, and *Macrobrachium grandimanus.*

Watershed Stewardship Rating

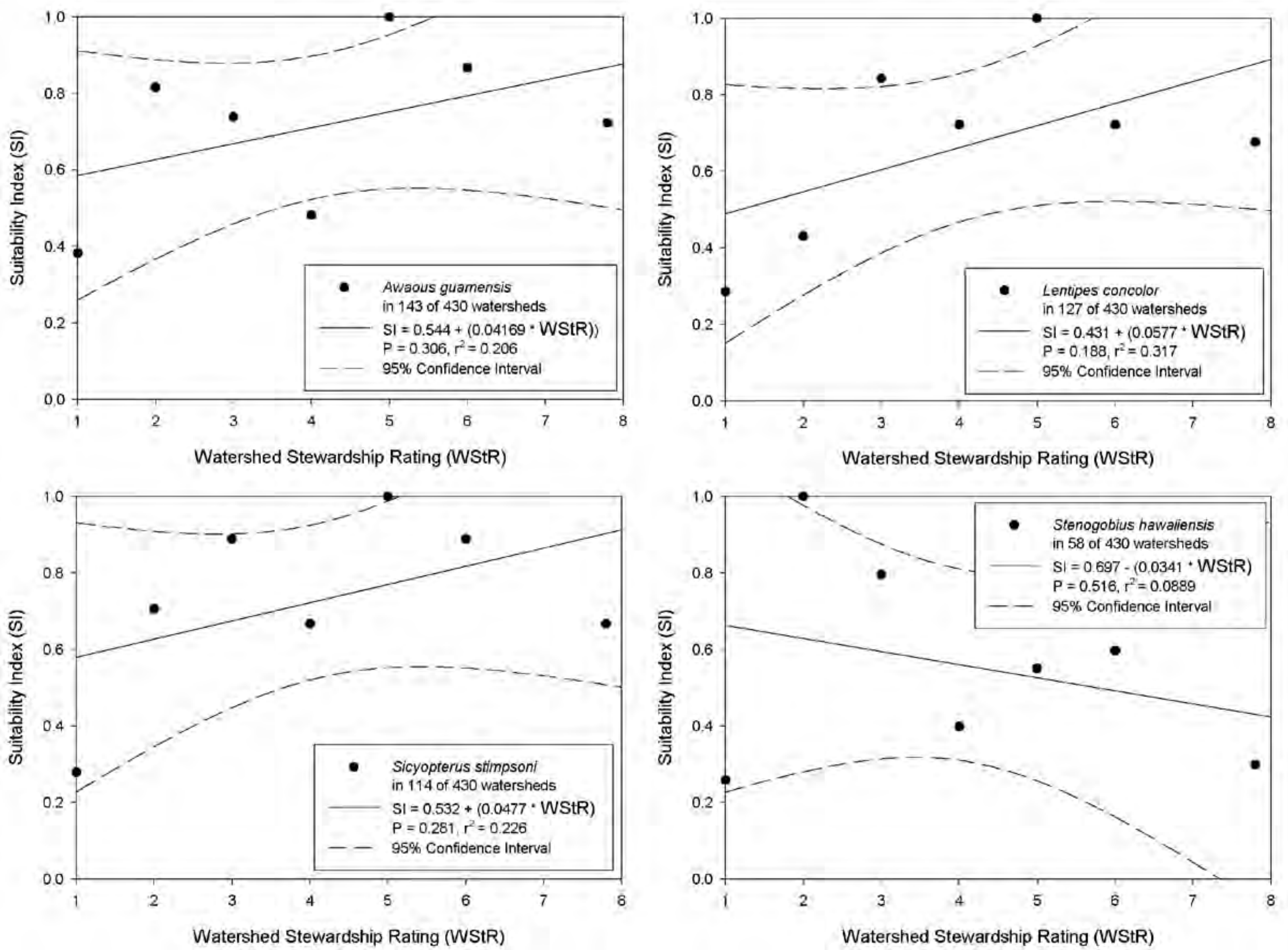


Figure 28. Suitability Indices for Watershed Stewardship Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

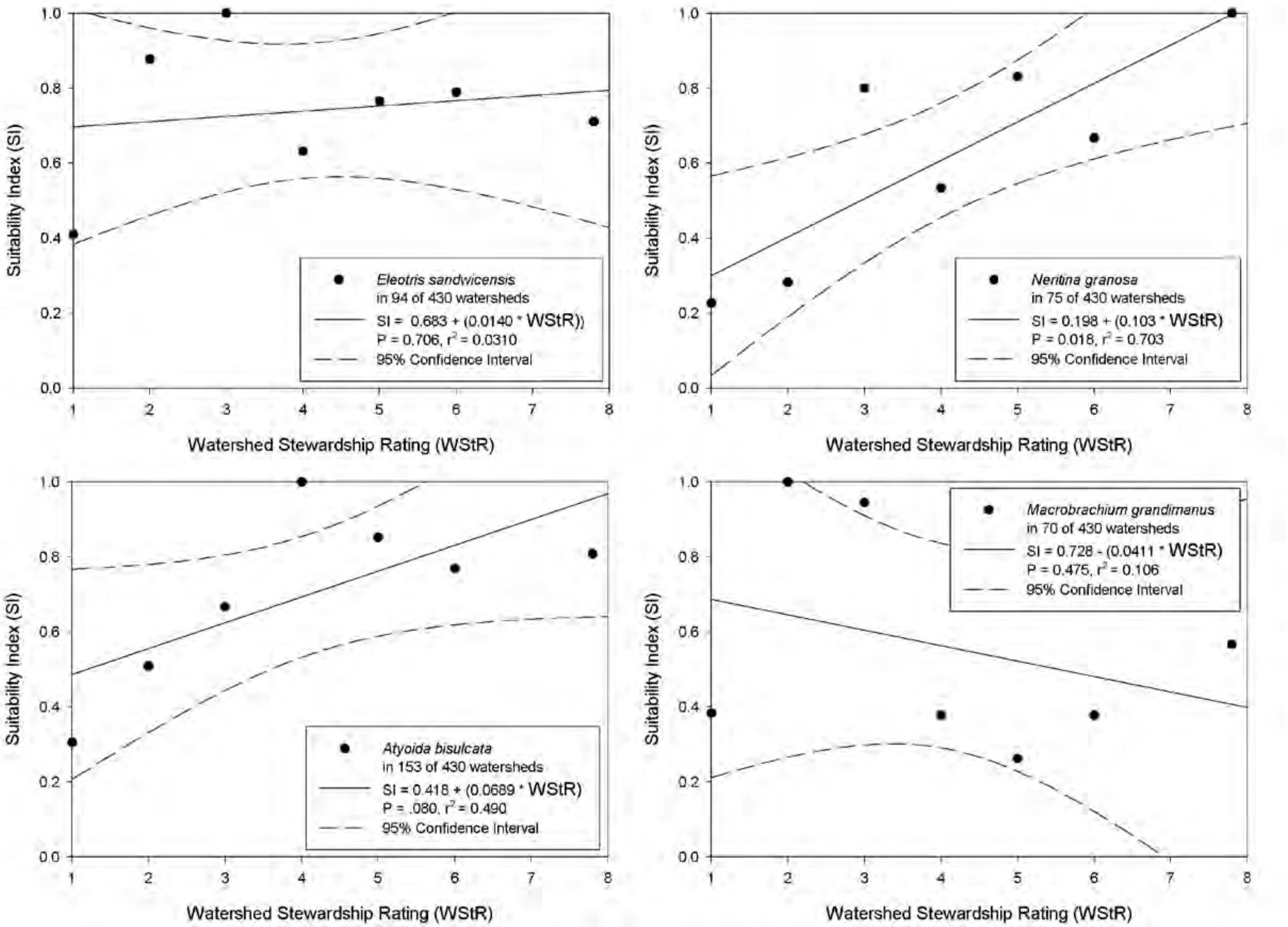


Figure 29. Suitability Indices for Watershed Stewardship Rating for *Eleotris sandwicensis*, *Neritina granosa*, *Atyoida bisulcata,* and *Macrobrachium grandimanus.*

Watershed Estuary and Nearshore Rating

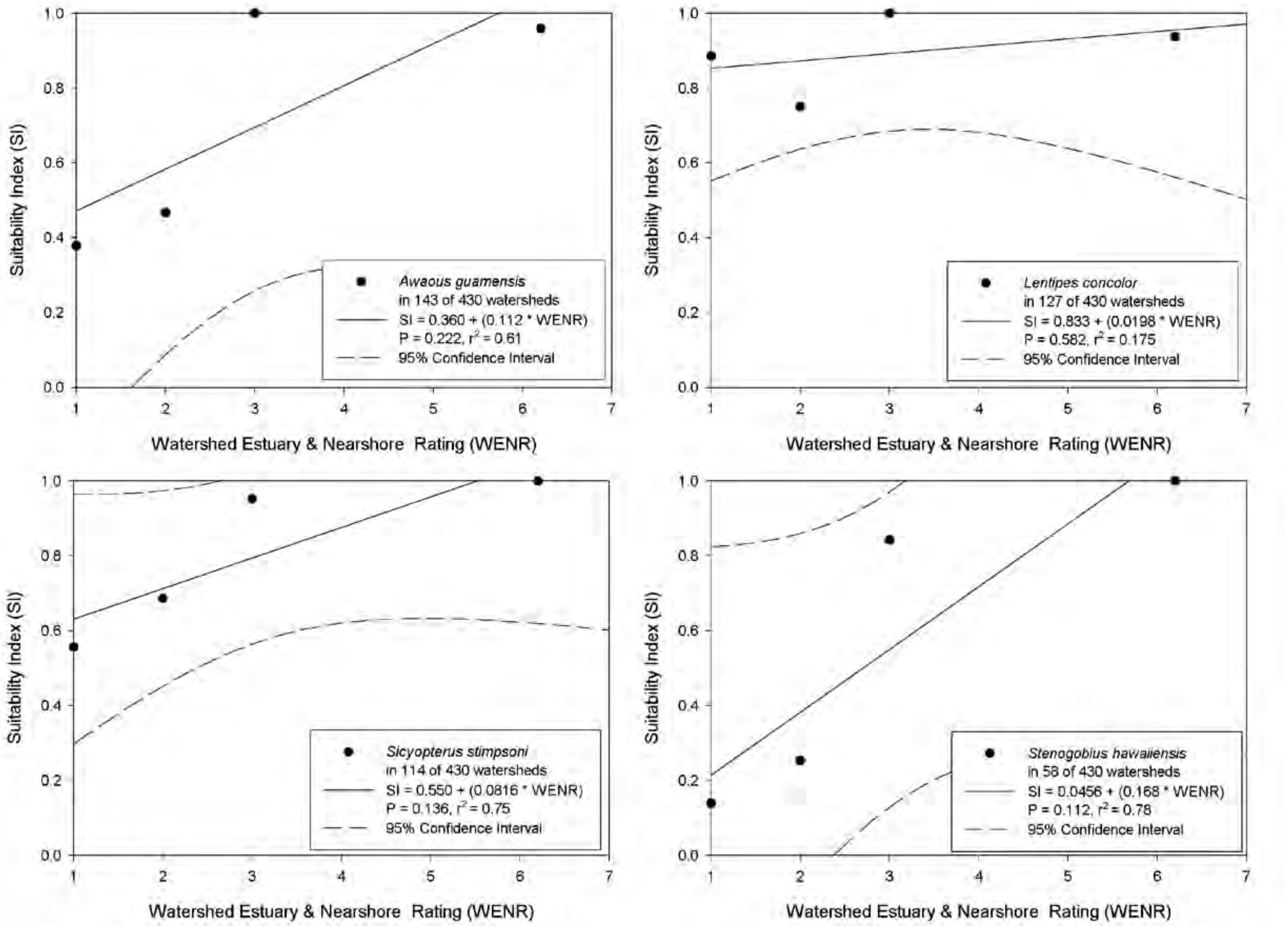


Figure 30. Suitability Indices for Watershed Estuary and Nearshore Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

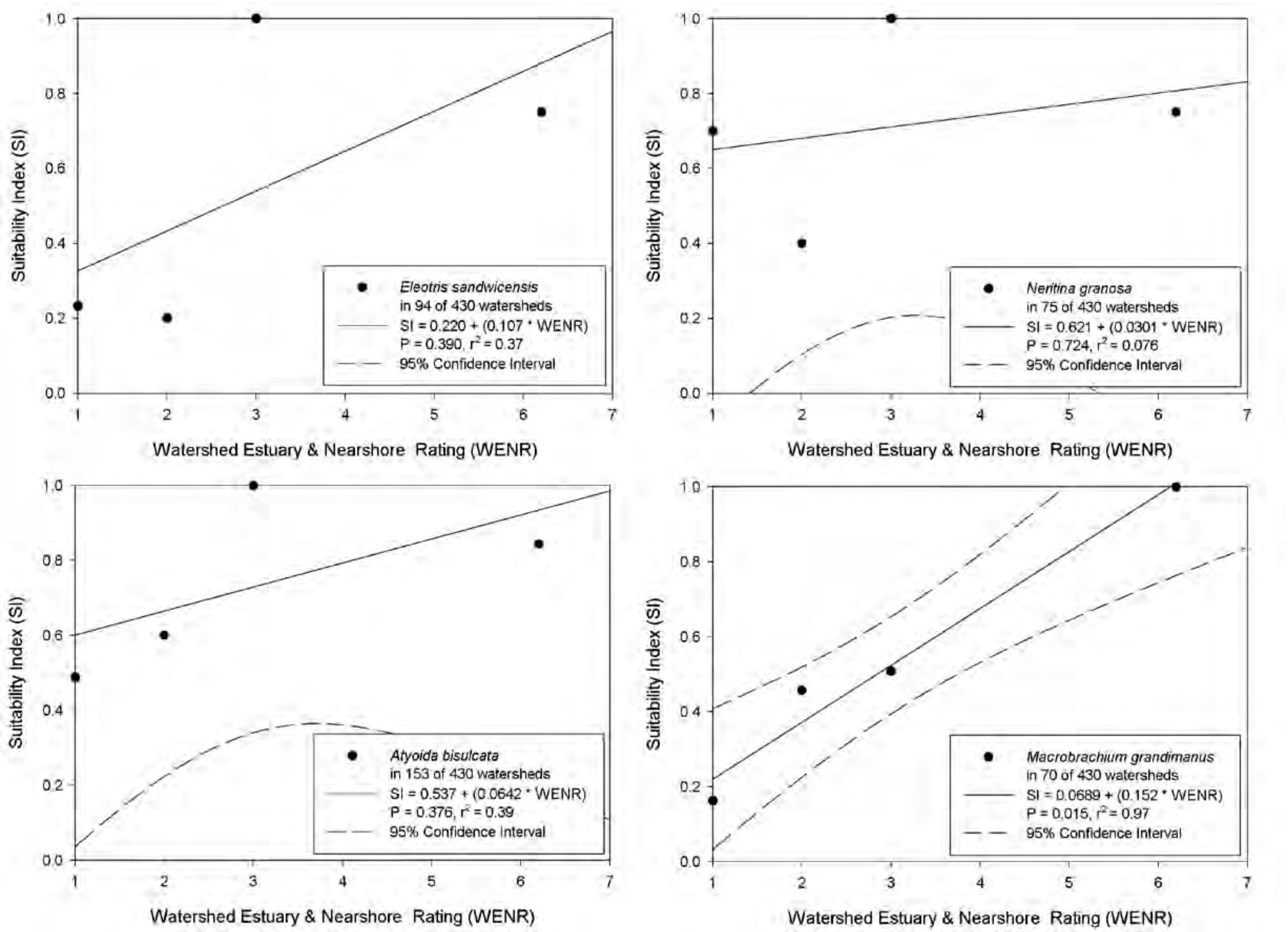


Figure 31. Suitability Indices for Watershed Estuary and Nearshore Rating for *Eleotris sandwicensis*, *Neritina granosa*, *Atyoida bisulcata*, and *Macrobrachium grandimanus.*

Watershed Land Quality Rating

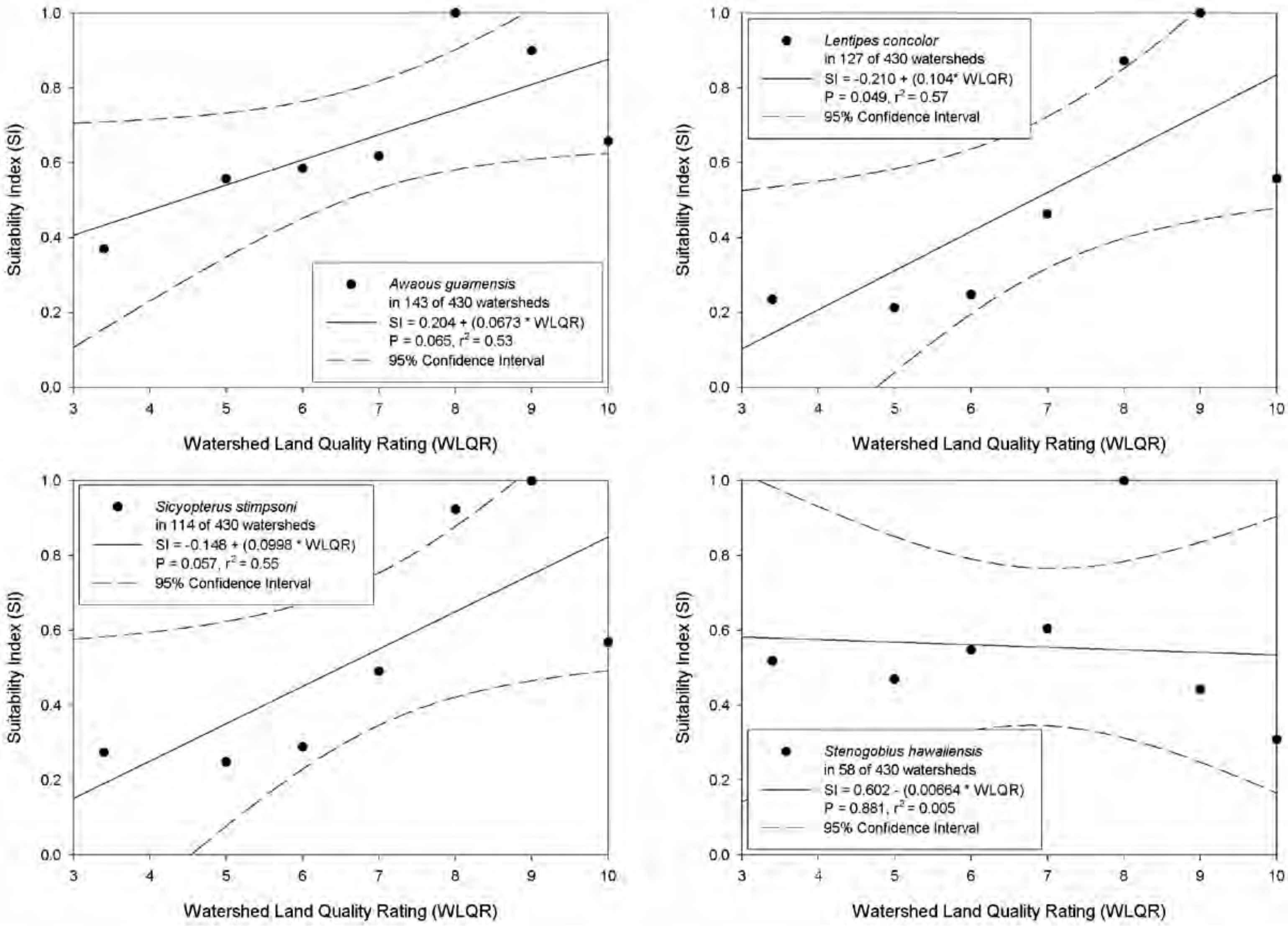


Figure 32. Suitability Indices for Watershed Land Quality Rating for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

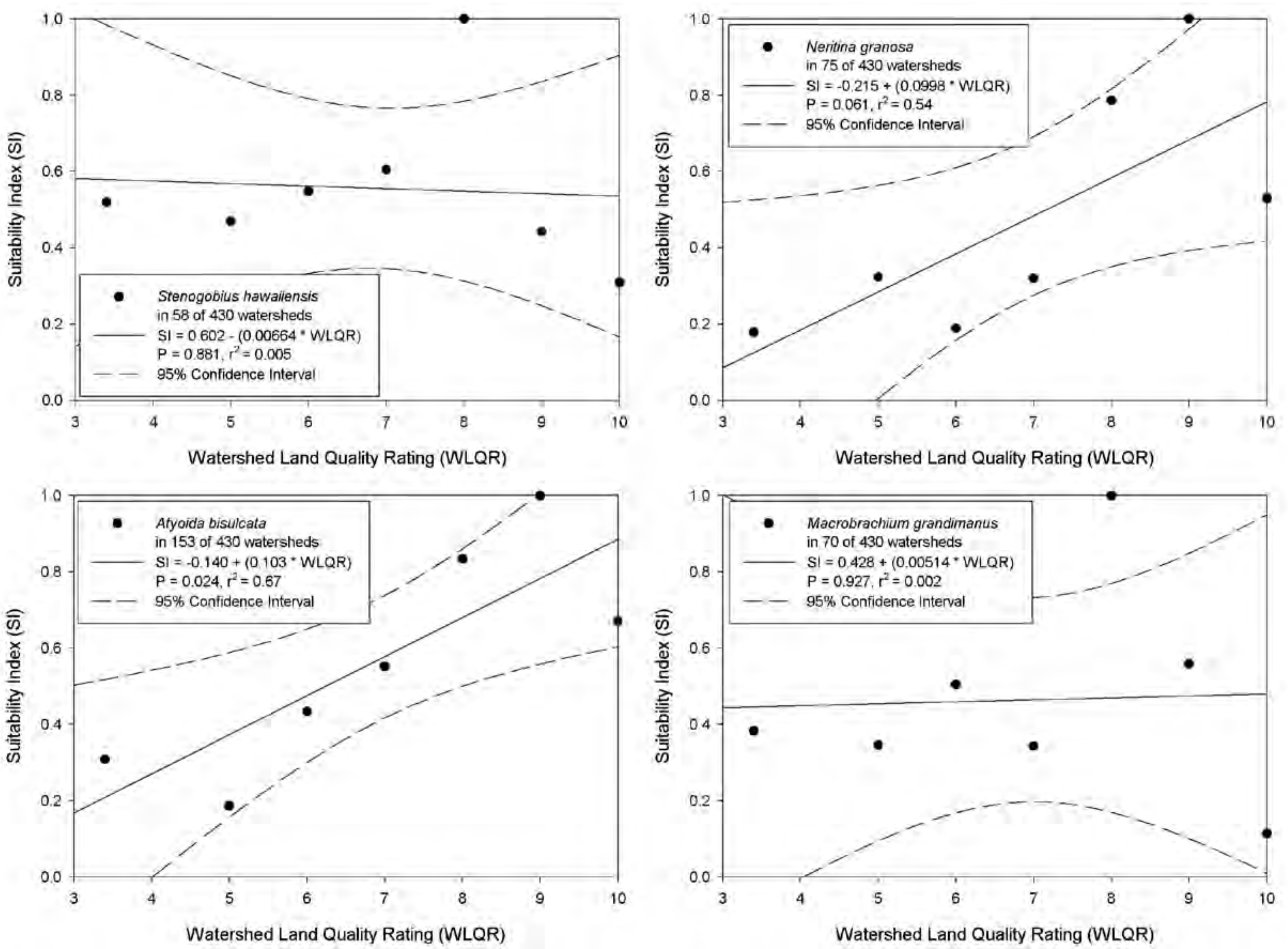


Figure 33. Suitability Indices for Watershed Land Quality Rating for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata*, and *Macrobrachium grandimanus.*

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).

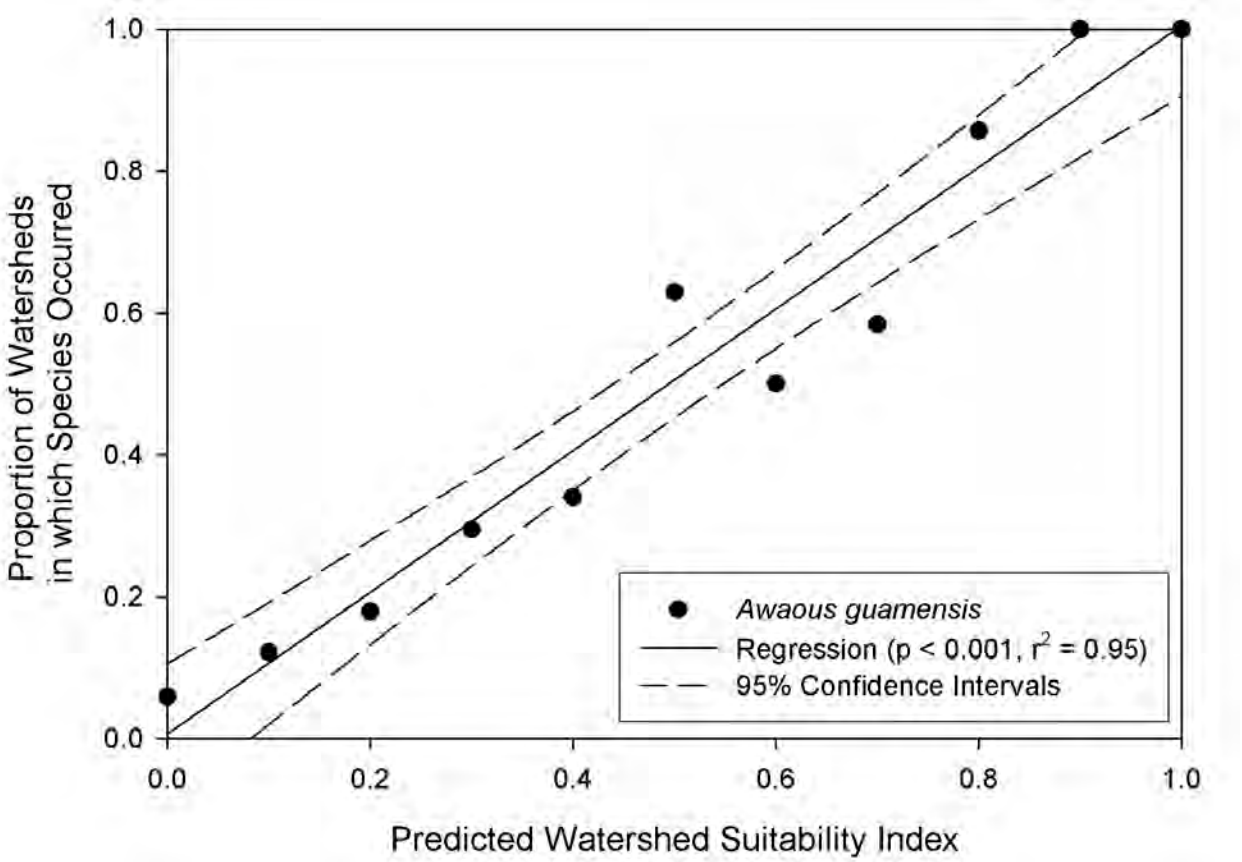


Figure 34. Proportion of the total watersheds where *Awaous guamensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Awaous guamensis*.

Lentipes concolor:

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

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

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).

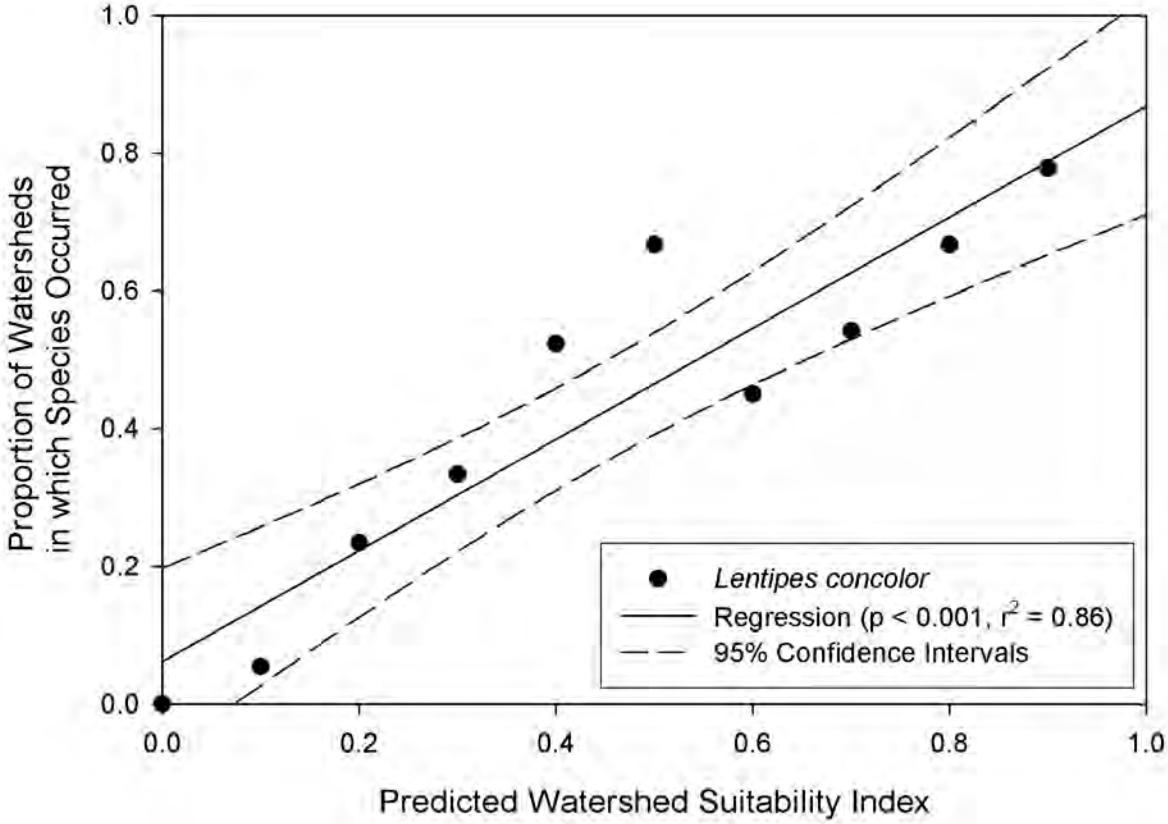


Figure 35. Proportion of the total watersheds where *Lentipes concolor* was observed within each 0.1 group of the Watershed Suitability Index equation for *Lentipes concolor*.

Sicyopterus stimpsoni:

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

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

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).

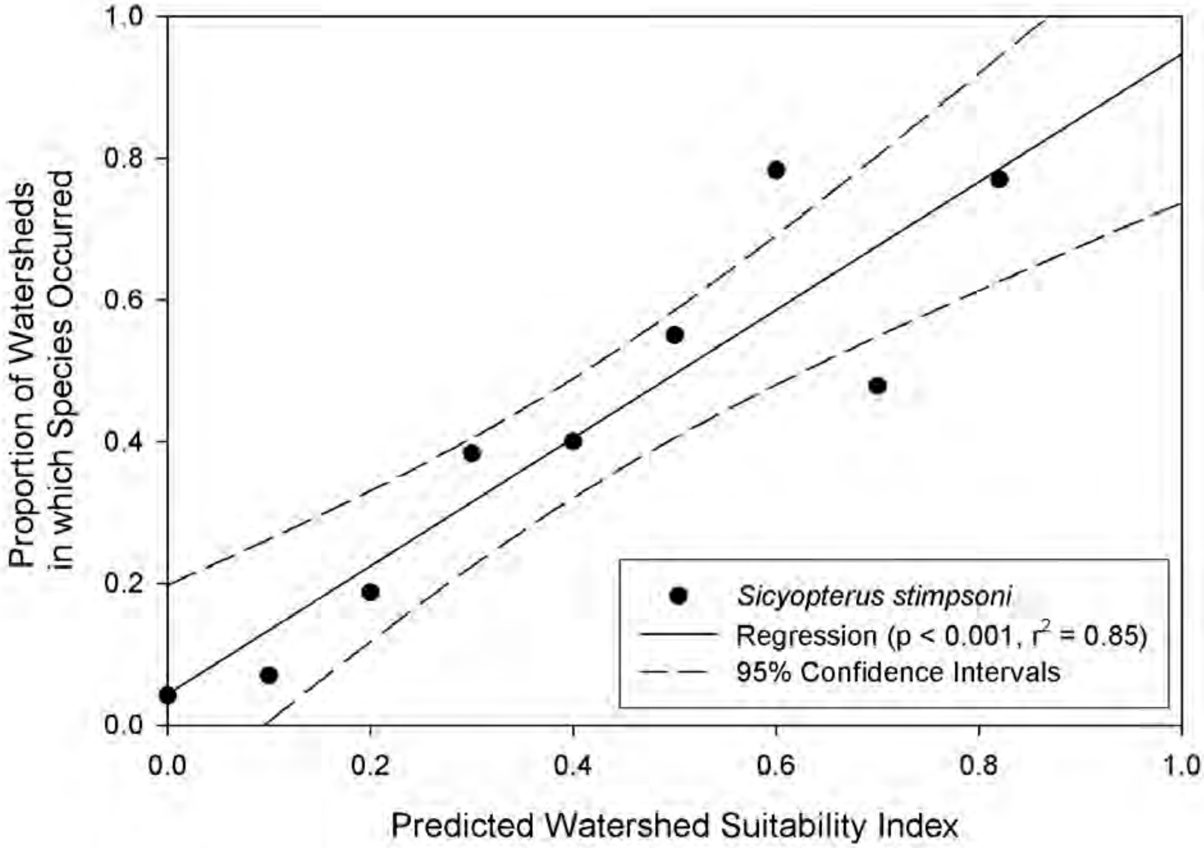


Figure 36. Proportion of the total watersheds where *Sicyopterus stimpsoni* was observed within each 0.1 group of the Watershed Suitability Index equation for *Sicyopterus stimpsoni*.

Stenogobius hawaiiensis:

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

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

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).

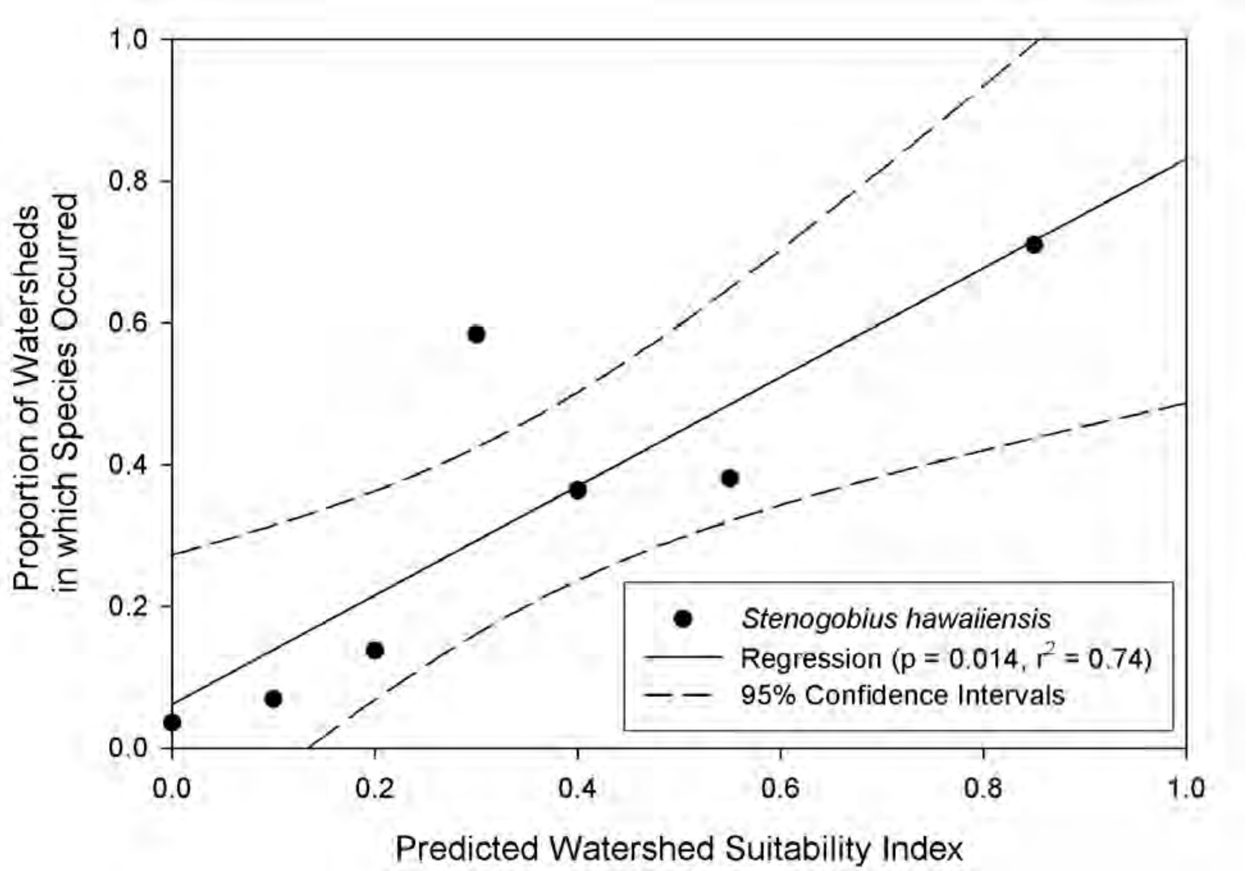


Figure 37. Proportion of the total watersheds where *Stenogobius hawaiiensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Stenogobius hawaiiensis*.

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).

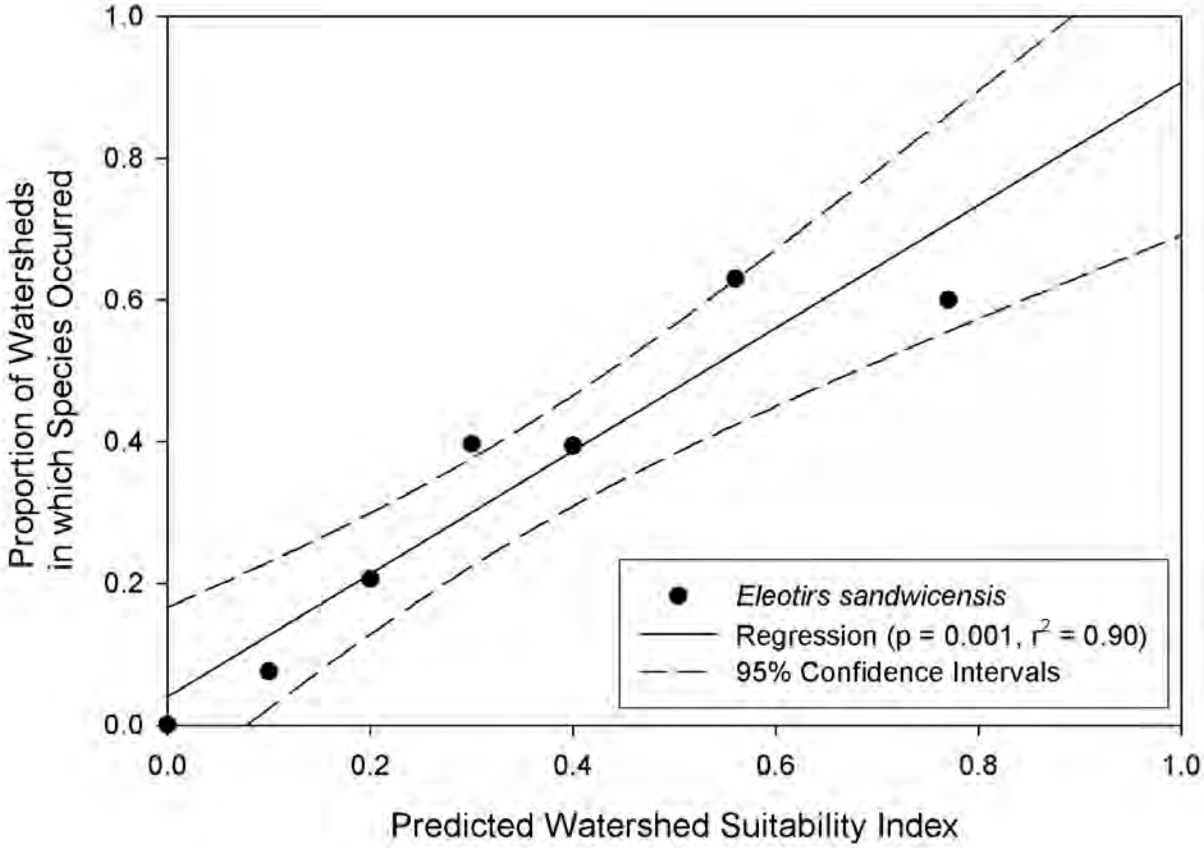


Figure 38. Proportion of the total watersheds where *Eleotris sandwicensis* was observed within each 0.1 group of the Watershed Suitability Index equation for *Eleotris sandwicensis*.

Neritina granosa:

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

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

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).

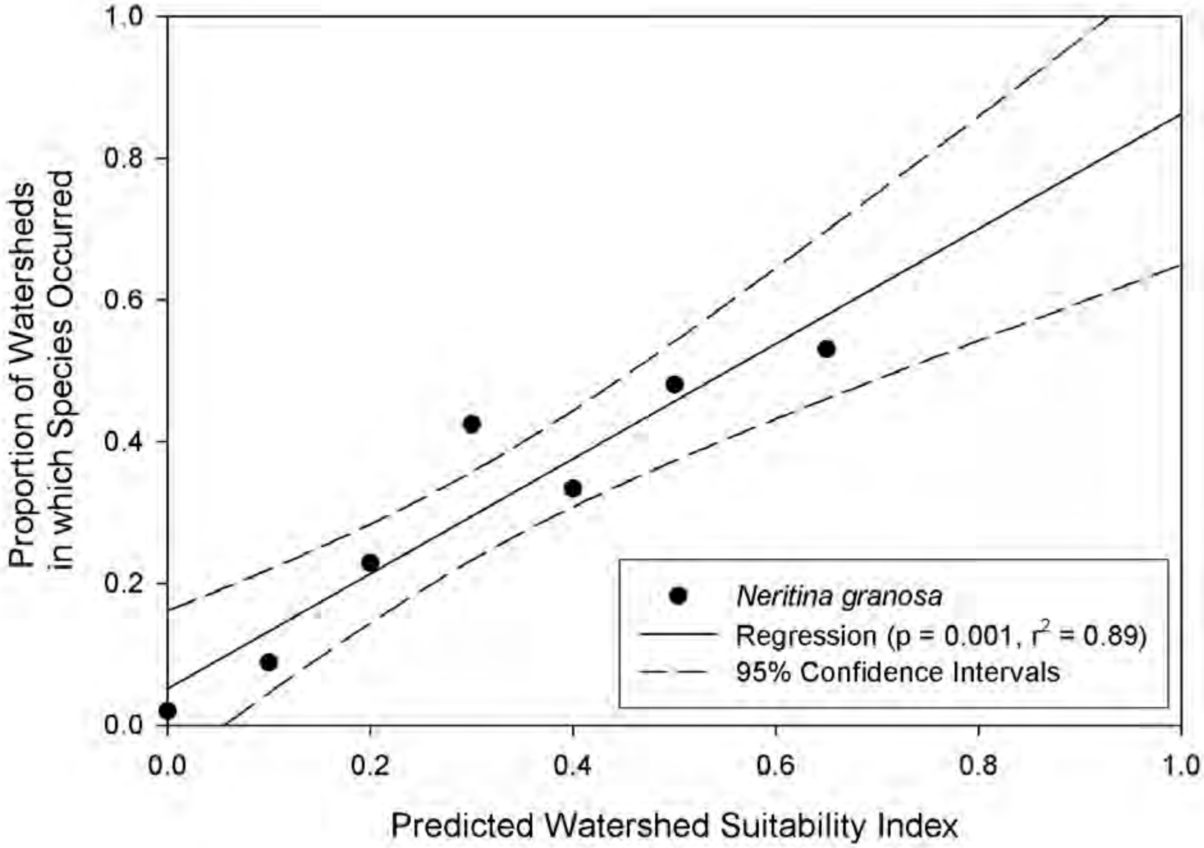


Figure 39. Proportion of the total watersheds where *Neritina granosa* was observed within each 0.1 group of the Watershed Suitability Index equation for *Neritina granosa*.

Atyoida bisulcata:

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

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

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).

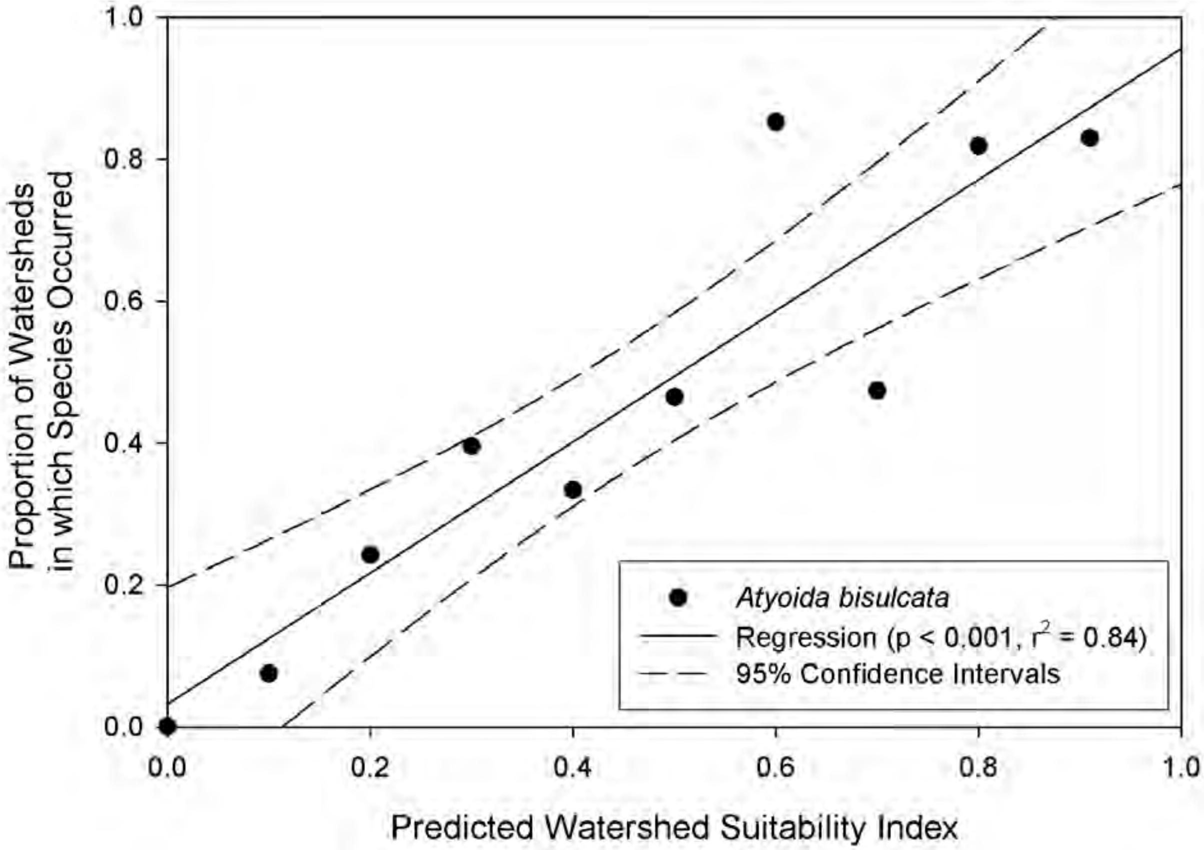


Figure 40. Proportion of the total watersheds where *Atyoida bisulcata* was observed within each 0.1 group of the Watershed Suitability Index equation for *Atyoida bisulcata*.

Macrobrachium grandimanus:

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

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

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).

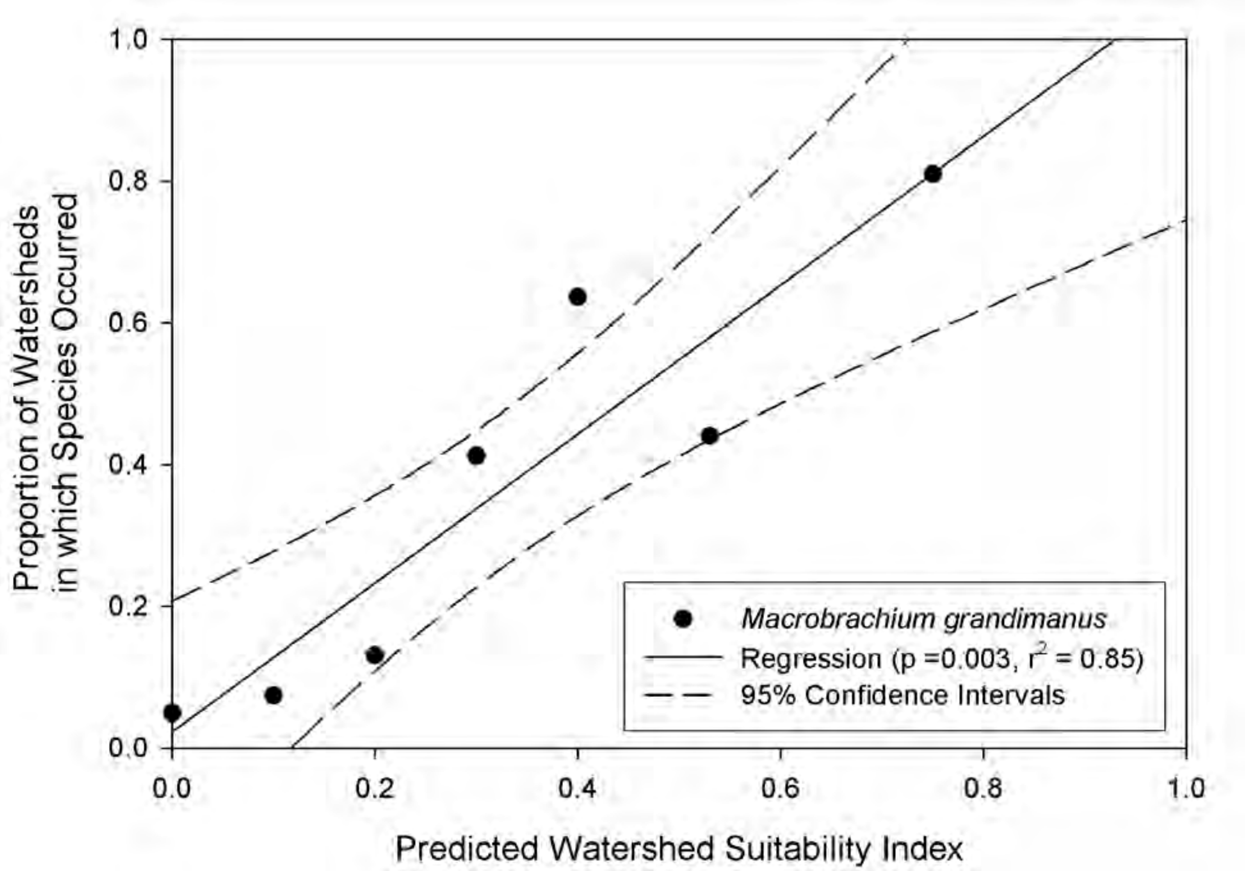


Figure 41. Proportion of the total watersheds where *Macrobrachium grandimanus* was observed within each 0.1 group of the Watershed Suitability Index equation for *Macrobrachium grandimanus*.

Stream Reach Scale: Elevation Suitability Indices

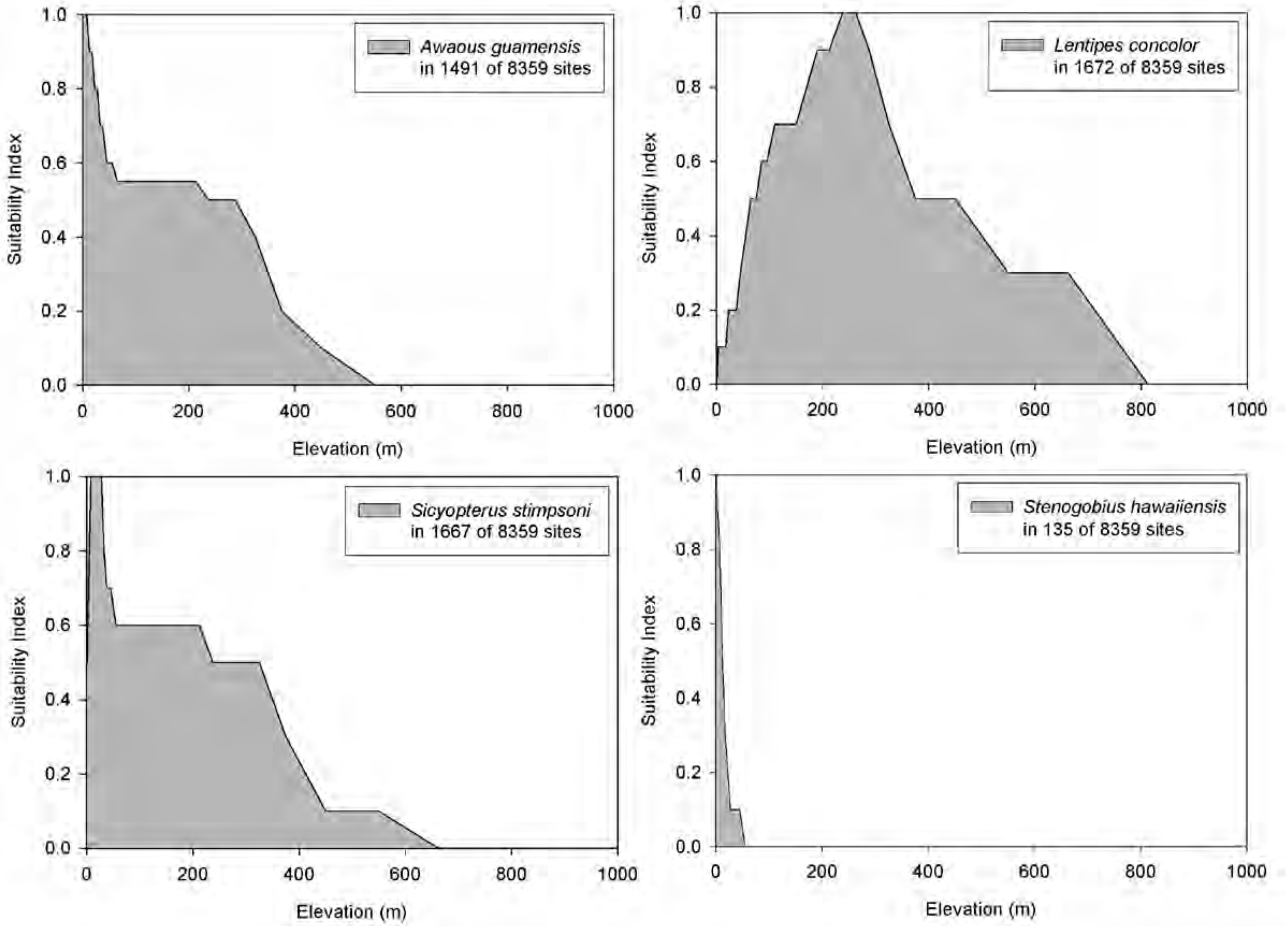


Figure 42. Suitability Indices for Elevation for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

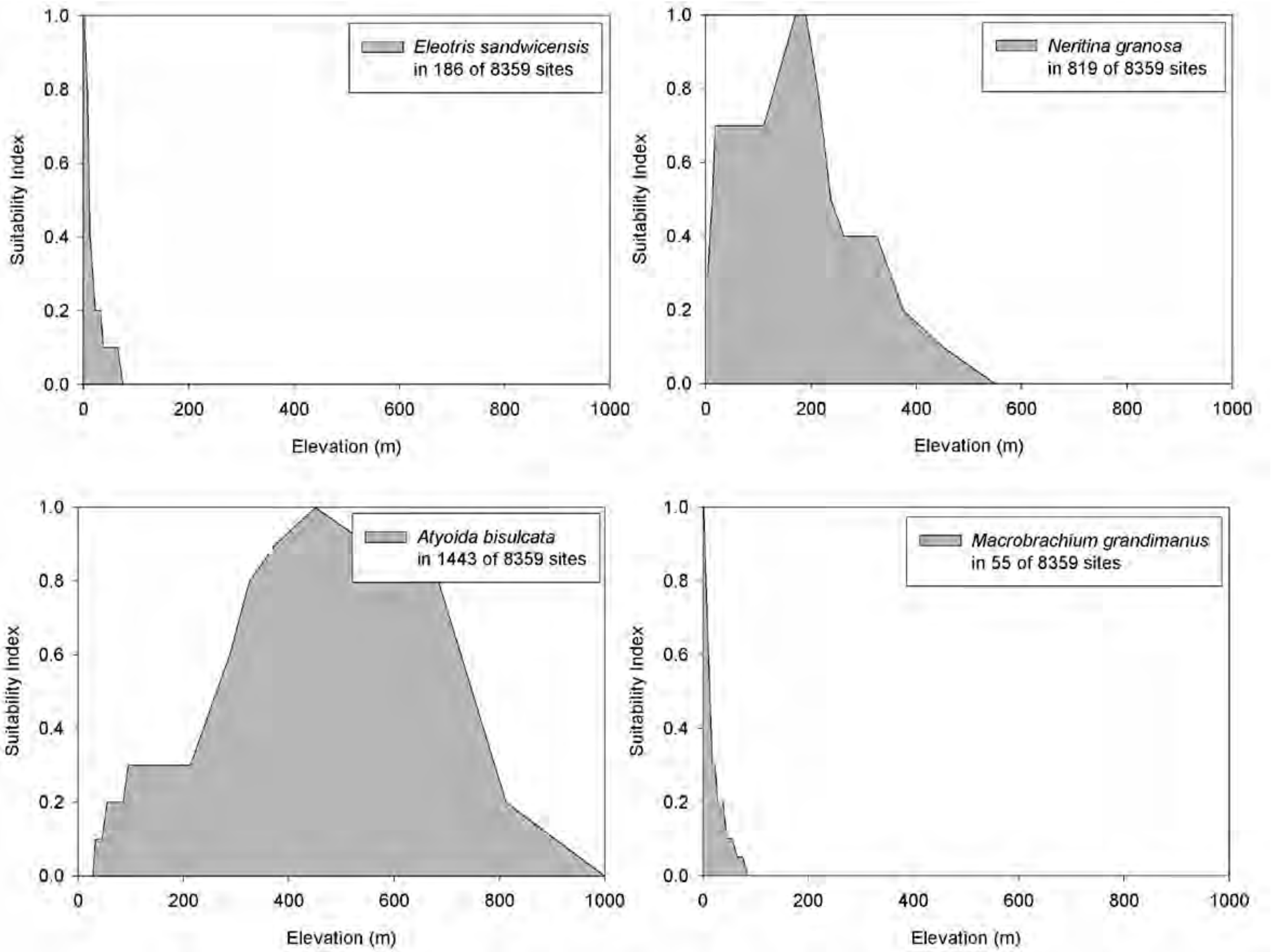


Figure 43. Suitability Indices for Elevation for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

Distance Inland Suitability Indices

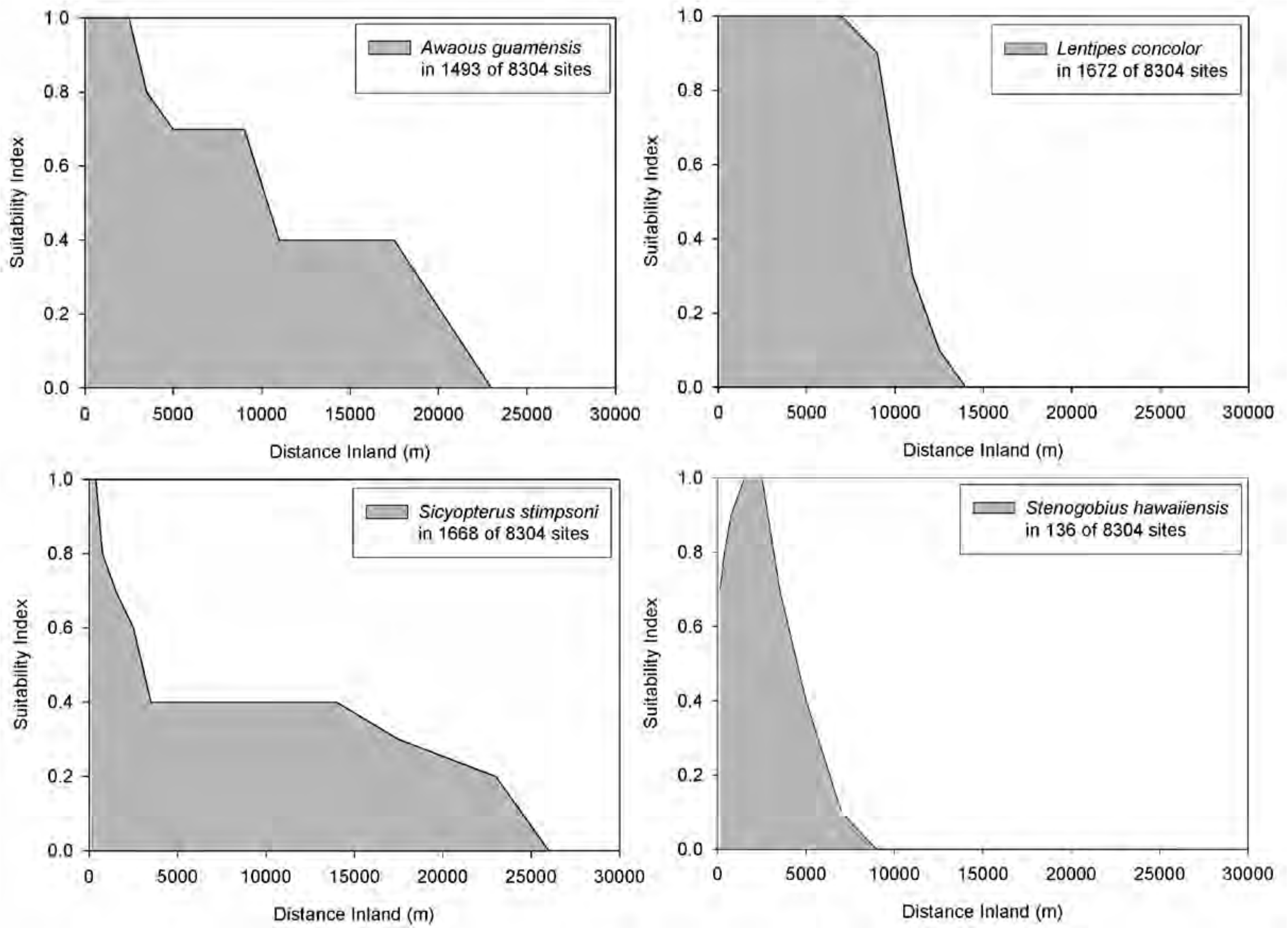


Figure 44. Suitability Indices for Distance Inland for *Awaous guamensis*, *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis.*

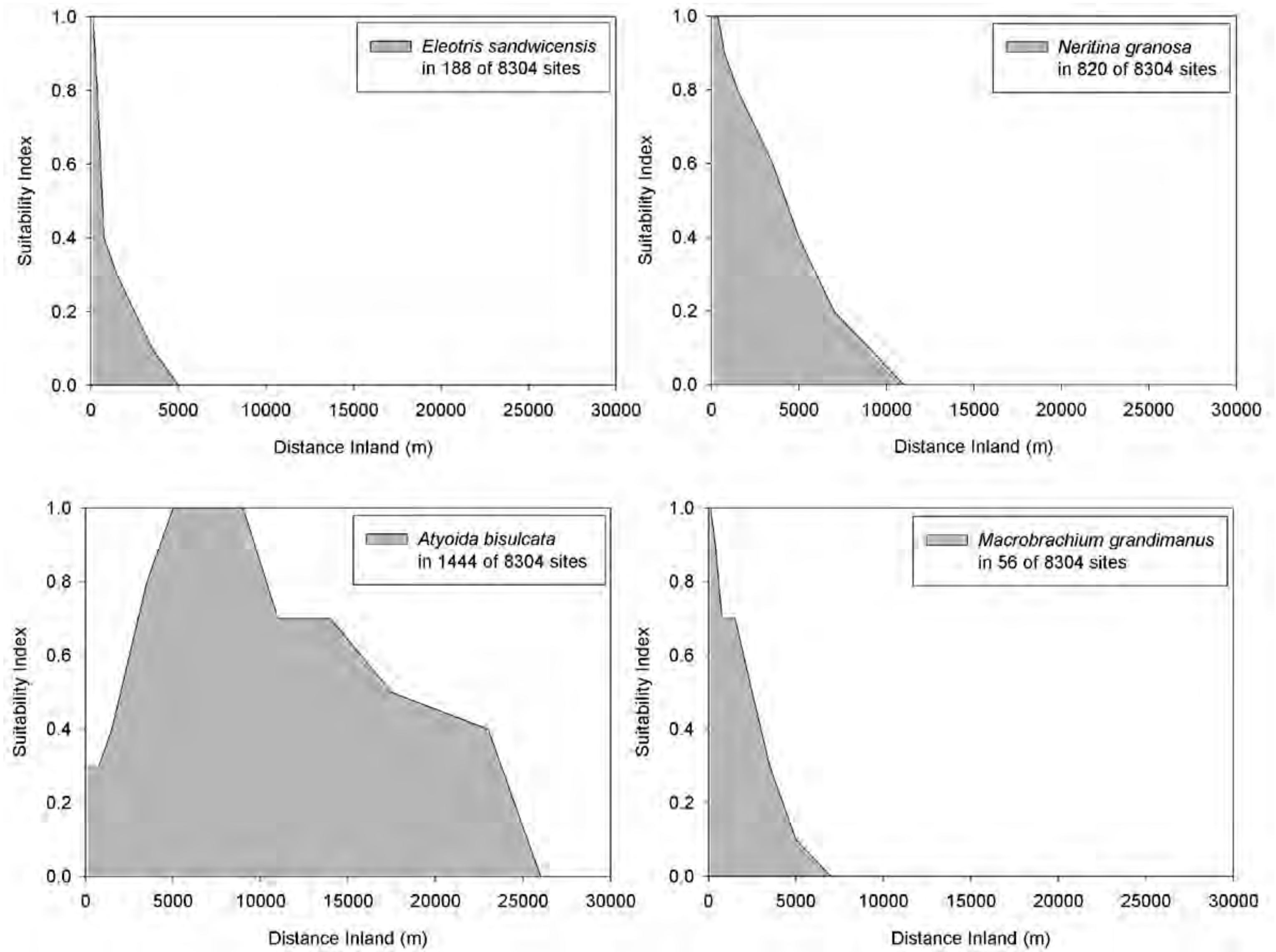


Figure 45. Suitability Indices for Distance Inland for *Eleotris sandwicensis, Neritina granosa, Atyoida bisulcata,* and *Macrobrachium grandimanus.*

Barrier Height Suitability Indices

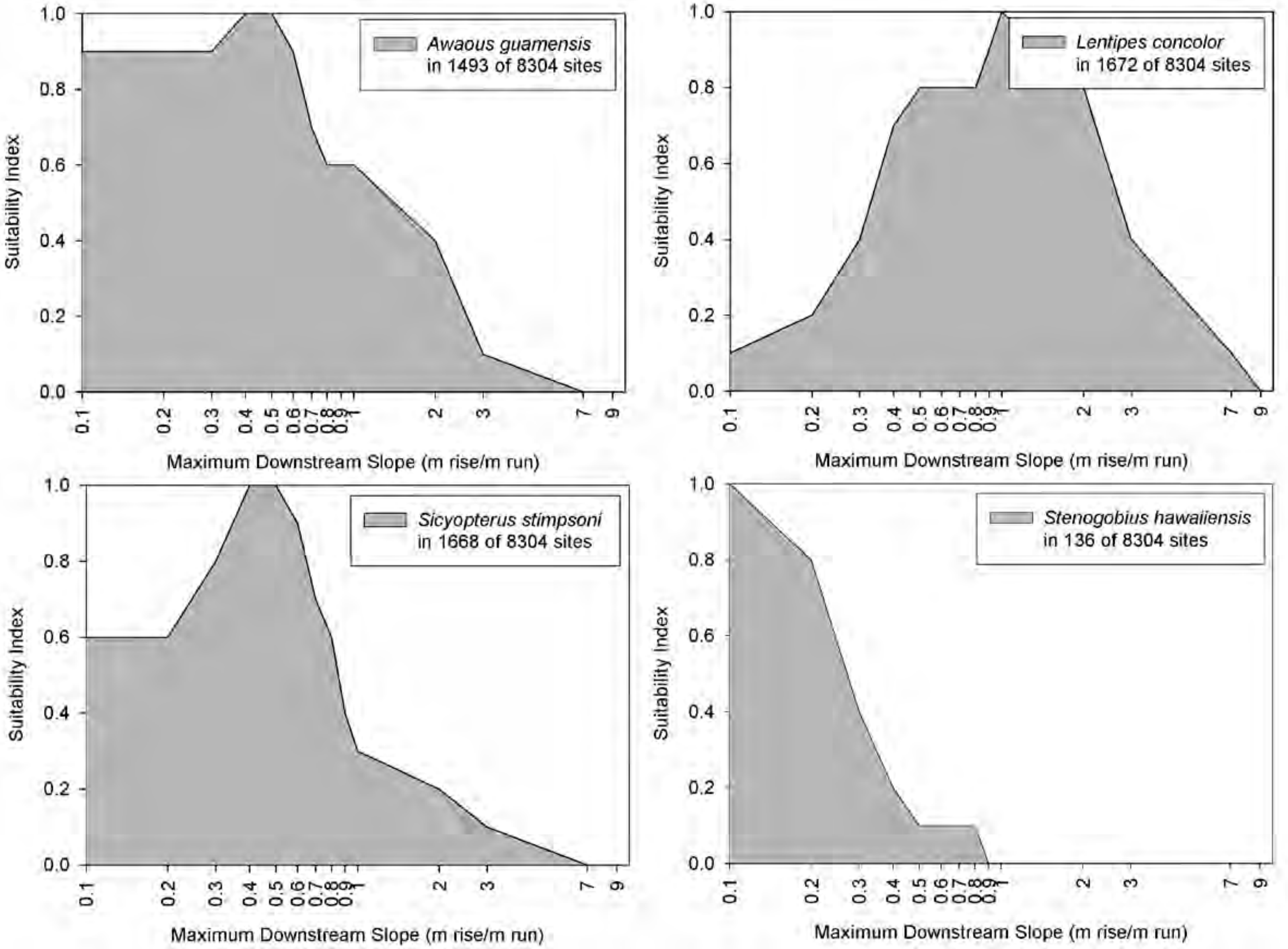


Figure 46. Suitability Indices for Barriers (maximum downstream slope over 10m distance) for *Awaous guamensis*, *Lentipes concolor, Sicyopterus stimpsoni,* and *Stenogobius hawaiiensis.*

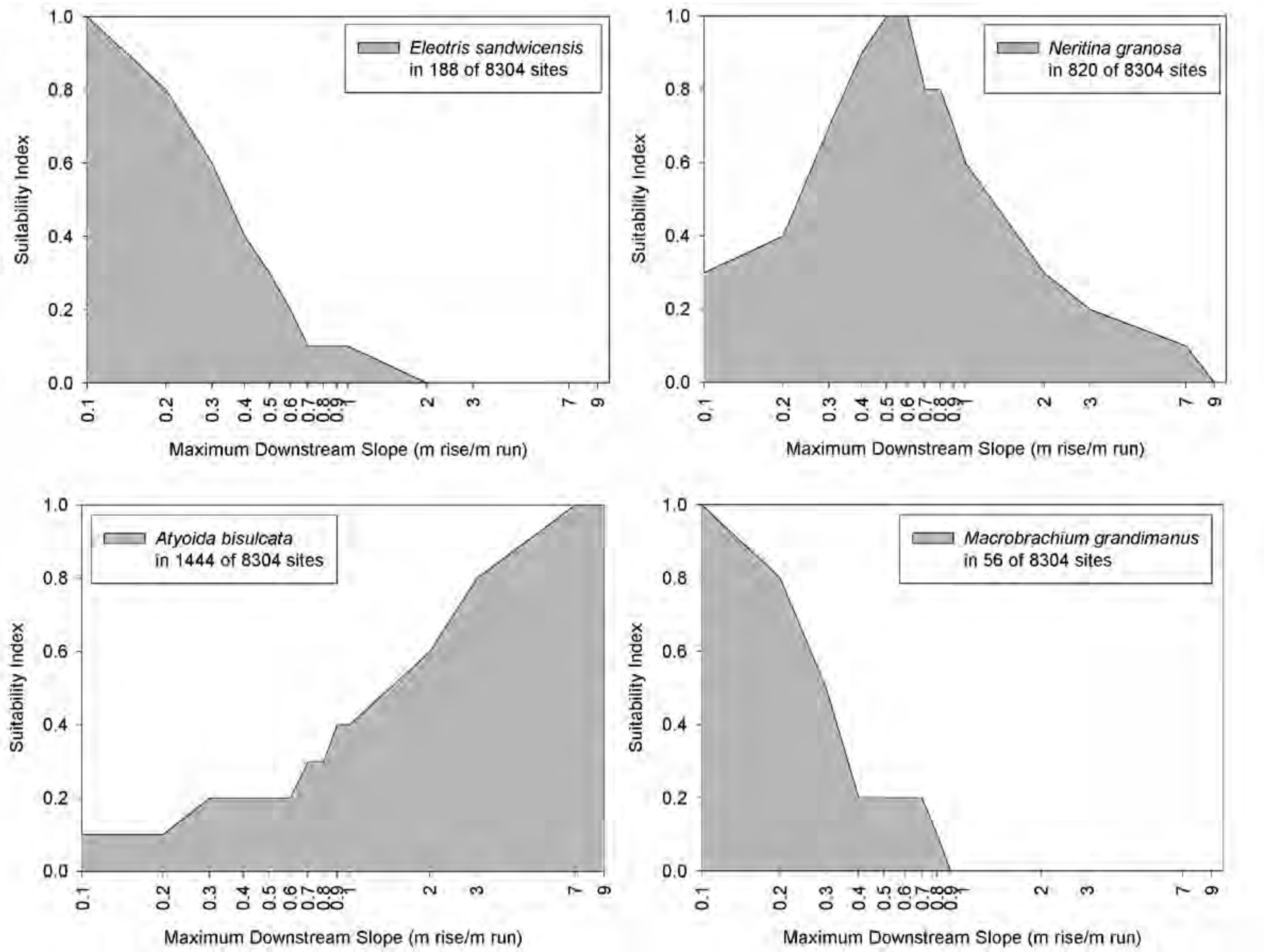


Figure 47. Suitability Indices for Barriers (maximum downstream slope over 10m distance) for *Eleotris sandwicensis*, *Neritina granosa*, *Atyoida bisulcata*, and *Macrobrachium grandimanus.*

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.

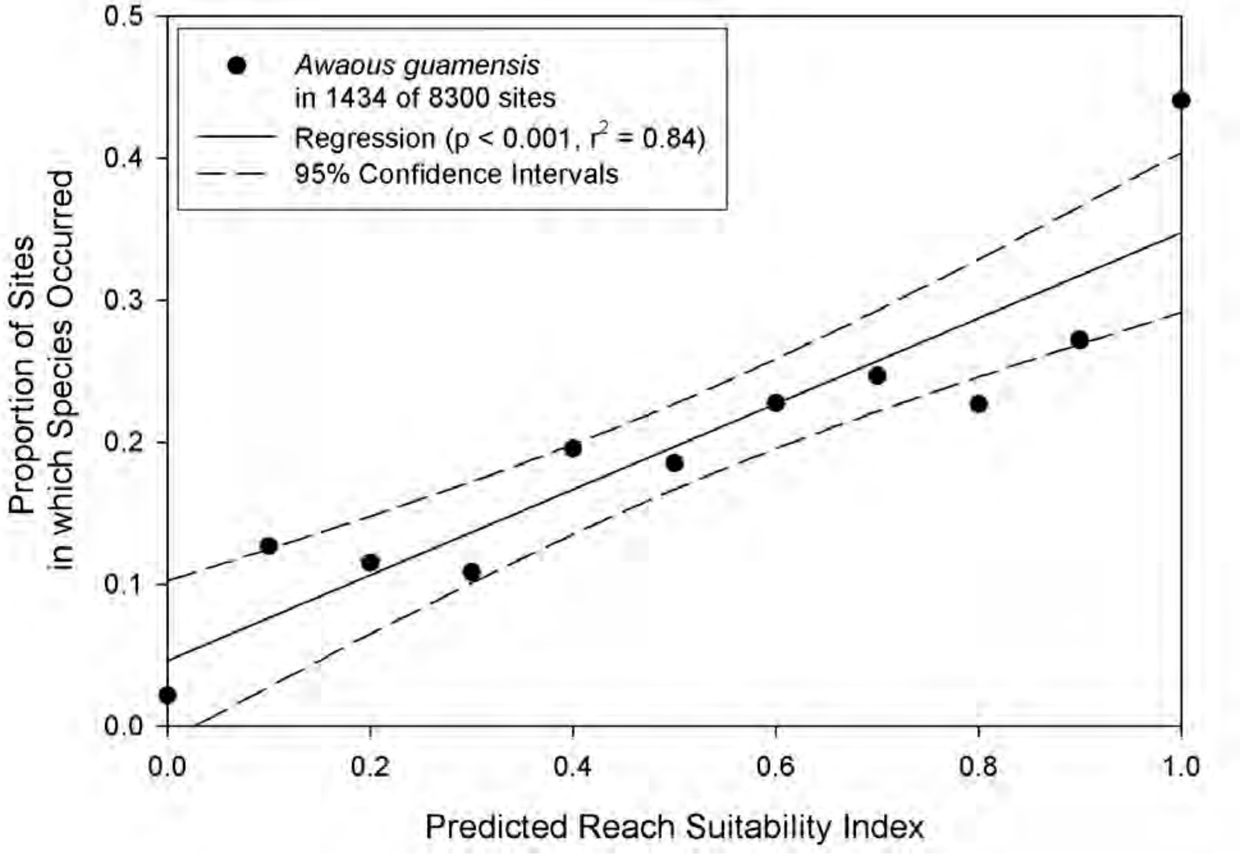


Figure 48. Proportion of the total sites where *Awaous guamensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Awaous guamensis*.

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.

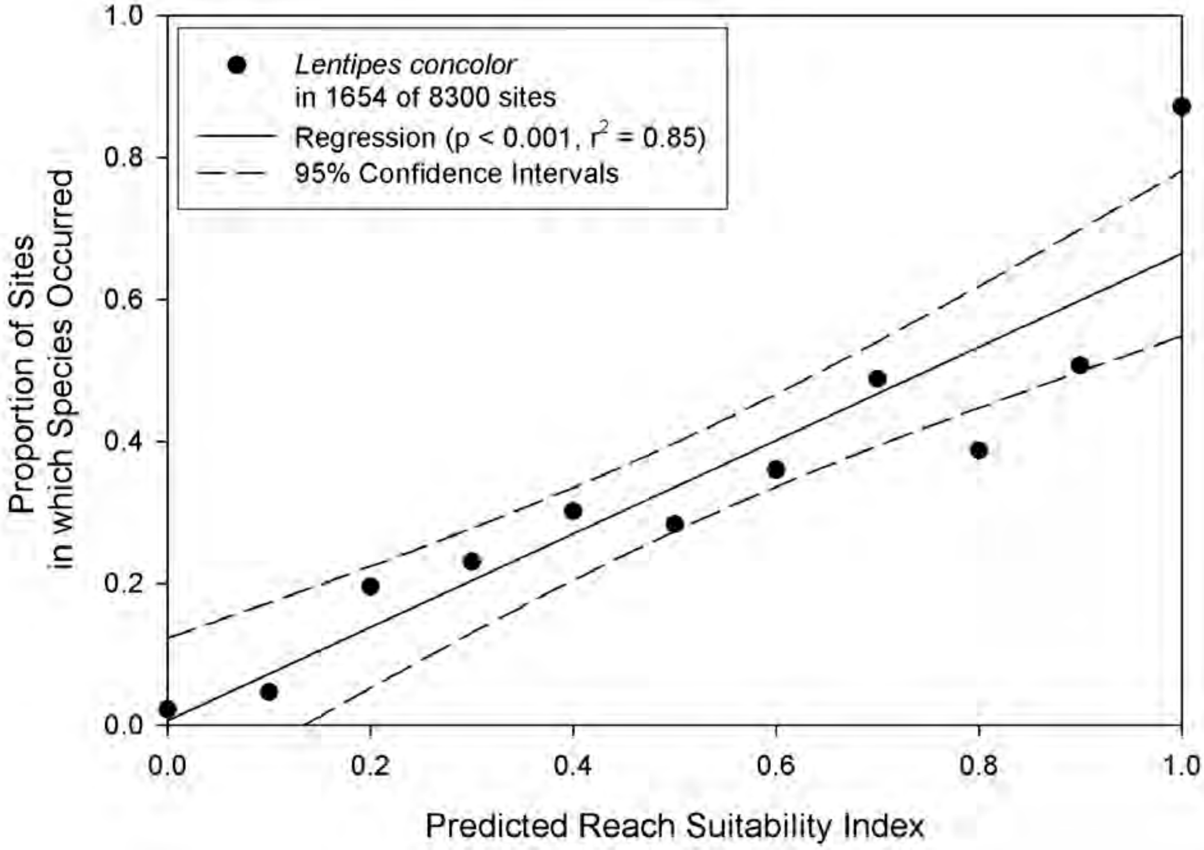


Figure 49. Proportion of the total sites where *Lentipes concolor* was observed within each 0.1 group of the Reach Suitability Index equation for *Lentipes concolor*.

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.

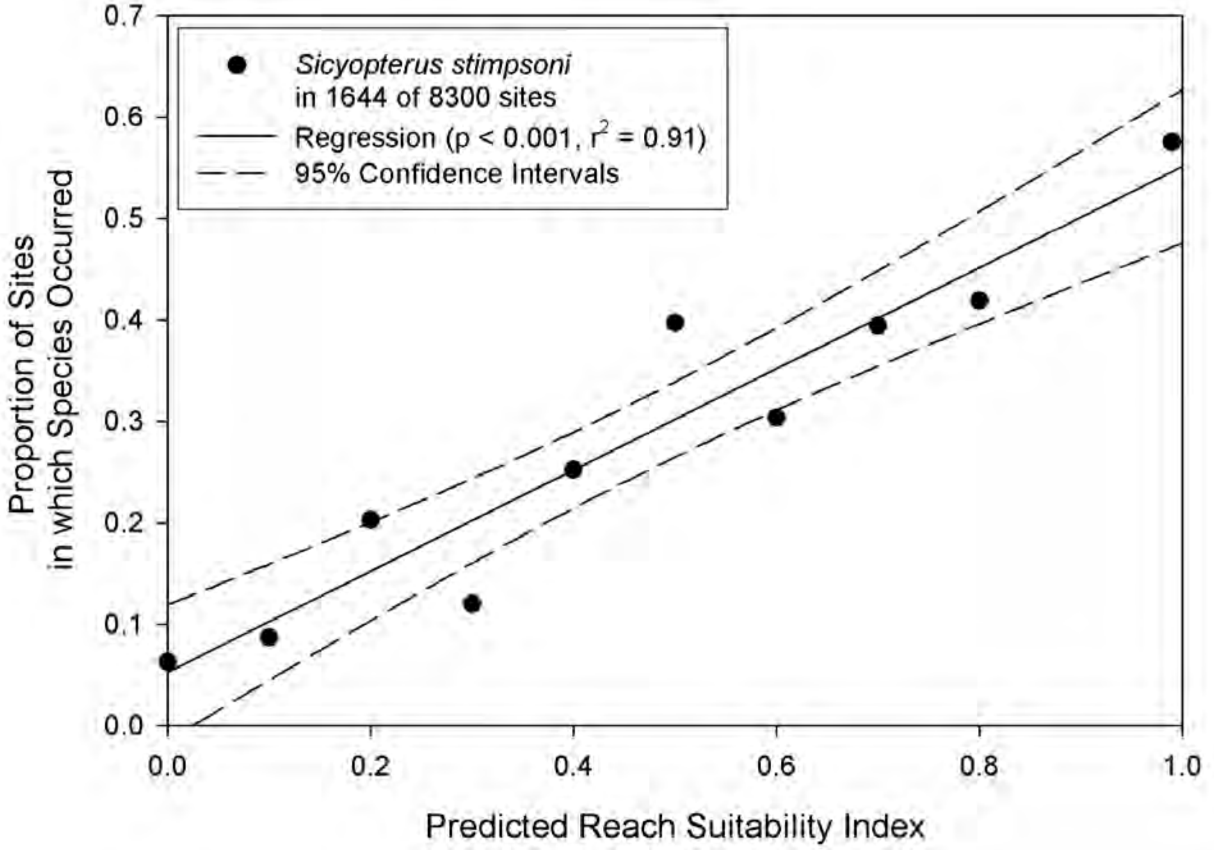


Figure 50. Proportion of the total sites where *Sicyopterus stimpsoni* was observed within each 0.1 group of the Reach Suitability Index equation for *Sicyopterus stimpsoni*.

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.

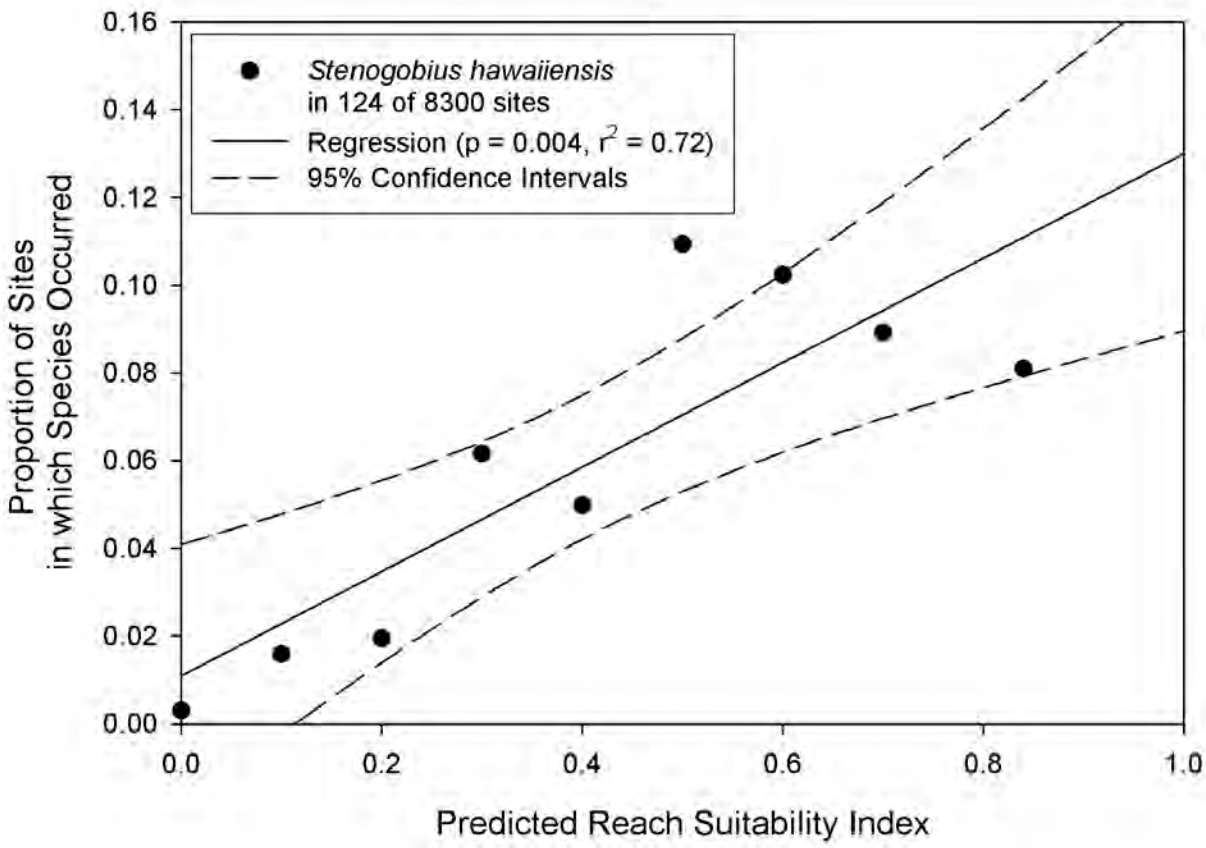


Figure 51. Proportion of the total sites where *Stenogobius hawaiiensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Stenogobius hawaiiensis*.

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.

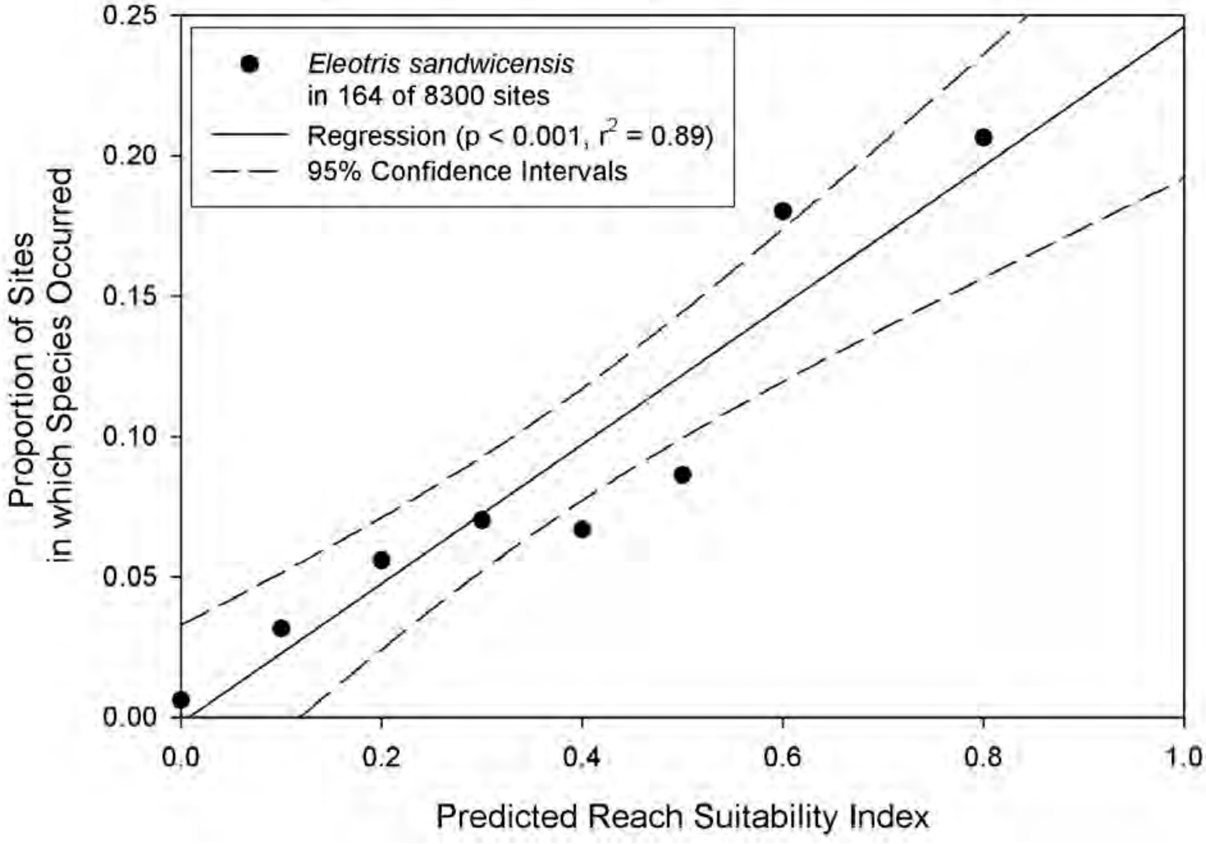


Figure 52. Proportion of the total sites where *Eleotris sandwicensis* was observed within each 0.1 group of the Reach Suitability Index equation for *Eleotris sandwicensis*.

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.

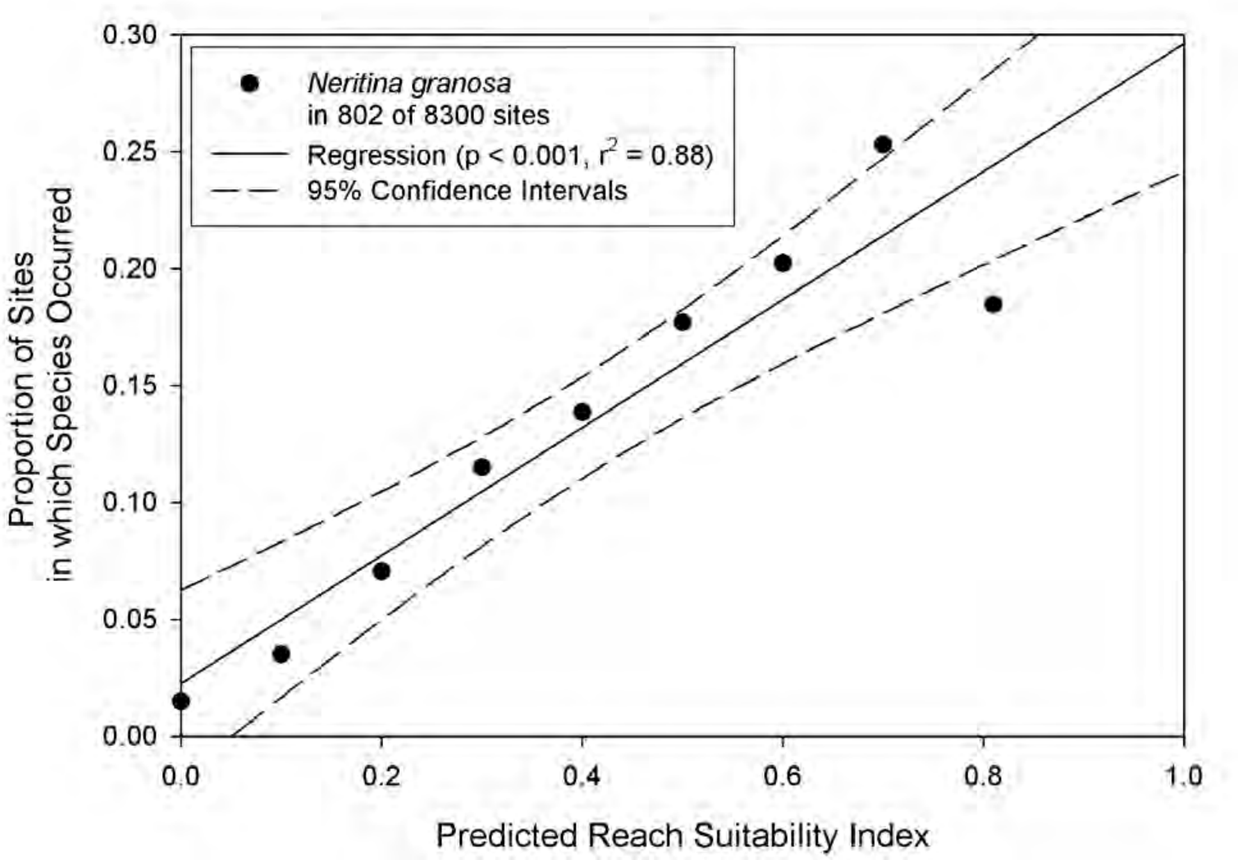


Figure 53. Proportion of the total sites where *Neritina granosa* was observed within each 0.1 group of the Reach Suitability Index equation for *Neritina granosa*.

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.

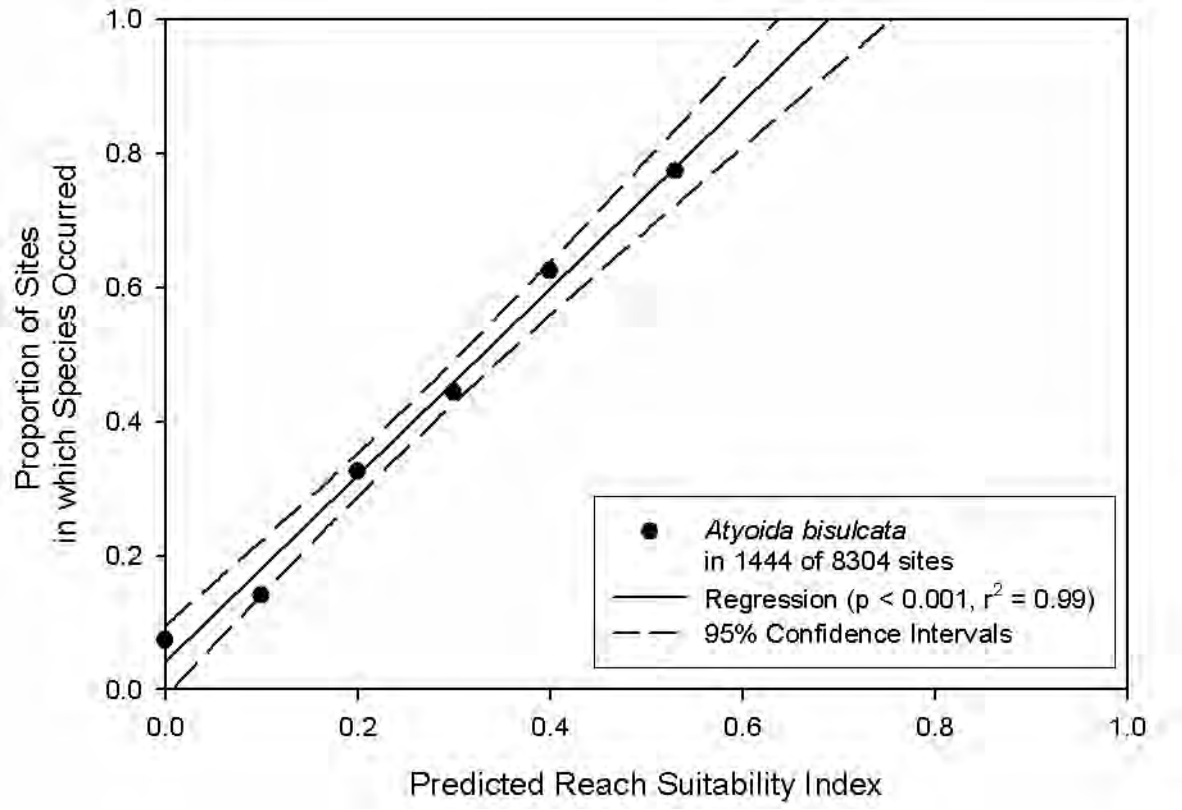


Figure 54. Proportion of the total sites where *Atyoida bisulcata* was observed within each 0.1 group of the Reach Suitability Index equation for *Atyoida bisulcata*.

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.

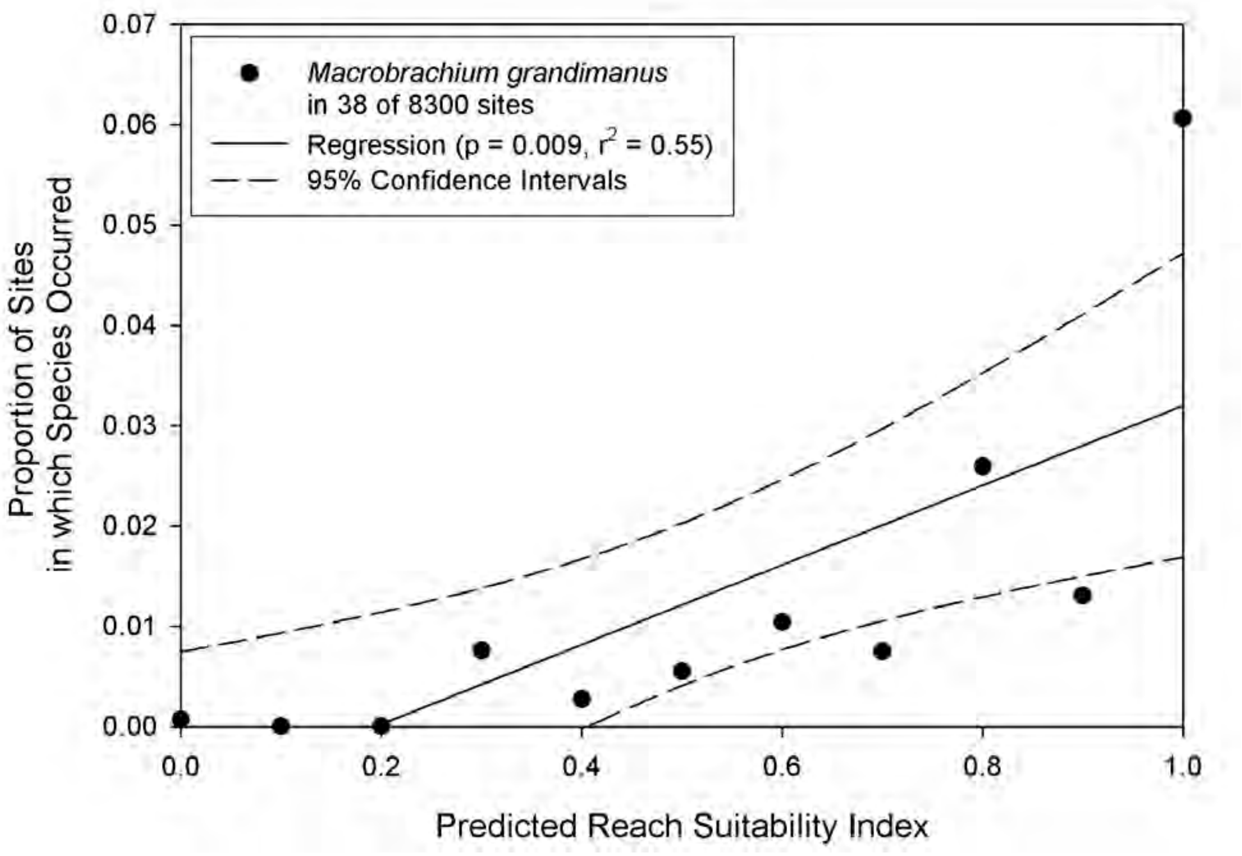


Figure 55. Proportion of the total sites where *Macrobrachium grandimanus* was observed within each 0.1 group of the Reach Suitability Index equation for *Macrobrachium grandimanus*.

Site level habitat availability:

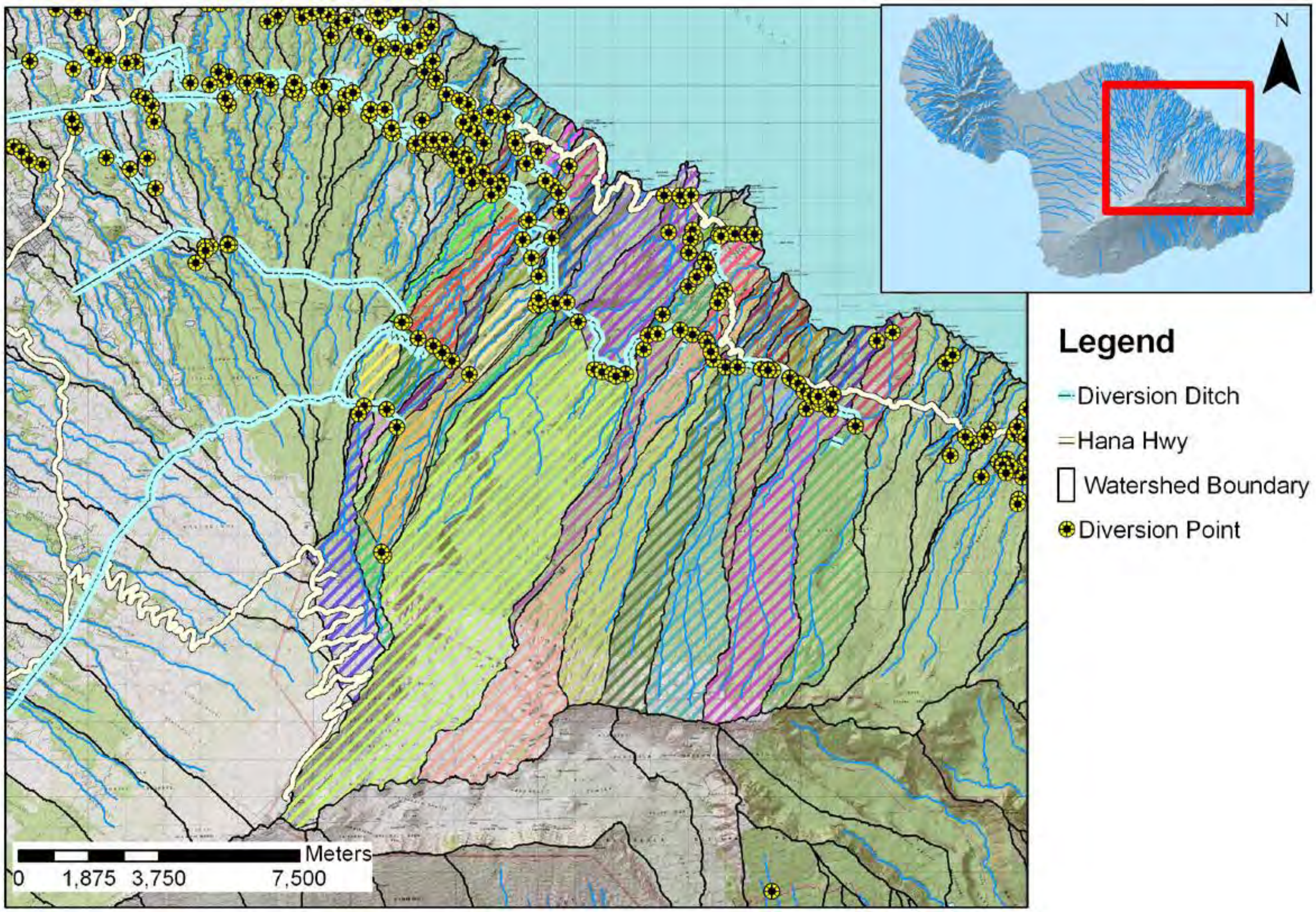


Figure 56. Zones related to the diversion systems on East Maui streams. Zones are the portion of a watershed upstream, between, or downstream of a diversion.

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, Hawaiʻi**. 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.

Kopili‘ula 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:

Pa‘akea Gulch is small, narrow, and steep with a small embayment (Report on Pa‘akea 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 Pa‘akea 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 Pa‘akea 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, Pa‘akea 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 Pa‘akea 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.

Kapā‘ula Gulch:

Kapā‘ula Gulch is small, narrow, and steep without an embayment (Report on Kapā‘ula 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 Kapā‘ula 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, Kapā‘ula 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 Kapā‘ula 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.

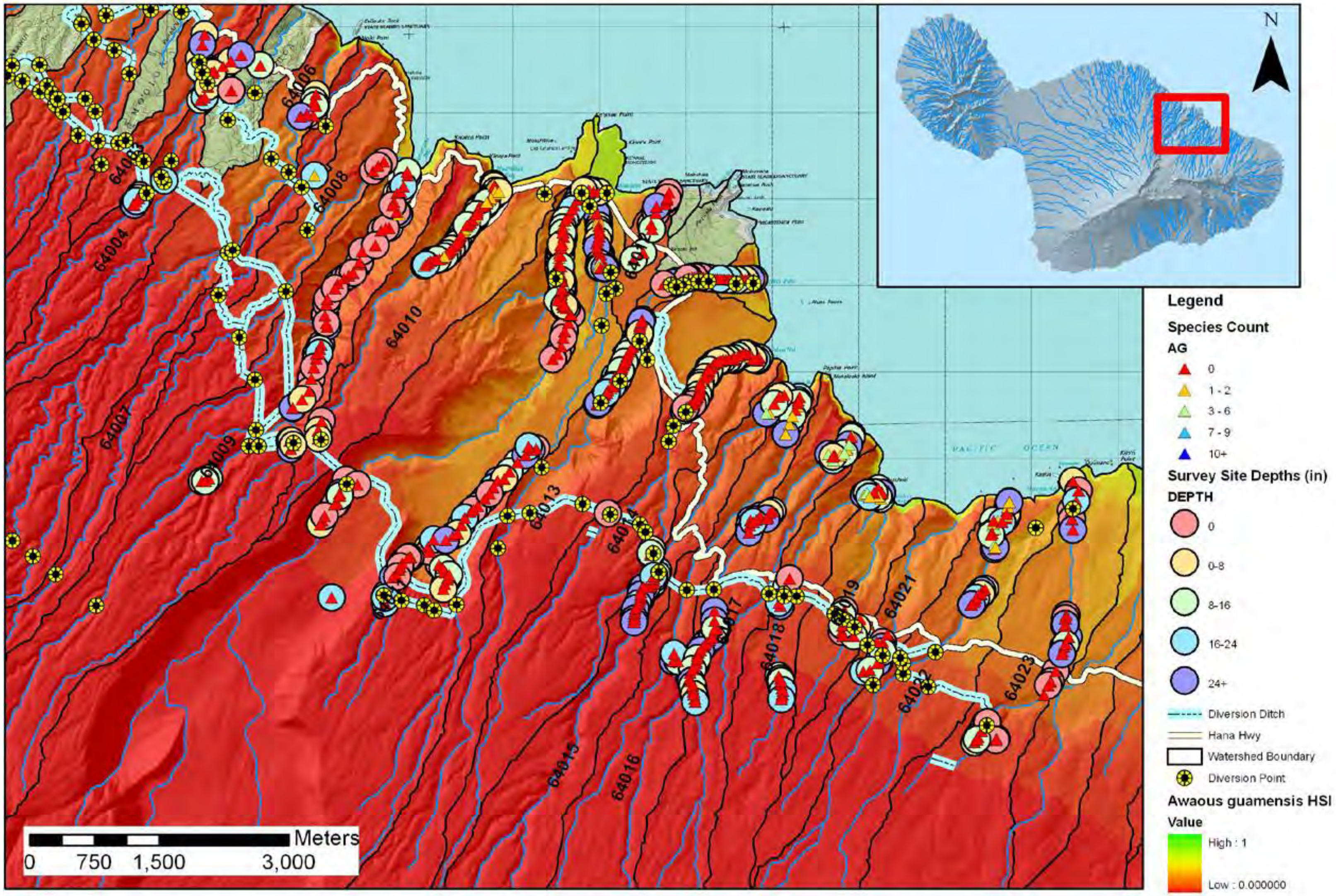


Figure 57. Predicted Habitat Suitability Index (HSI) for *Awaous guamensis*. Map includes survey site depths and count of *Awaous guamensis* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

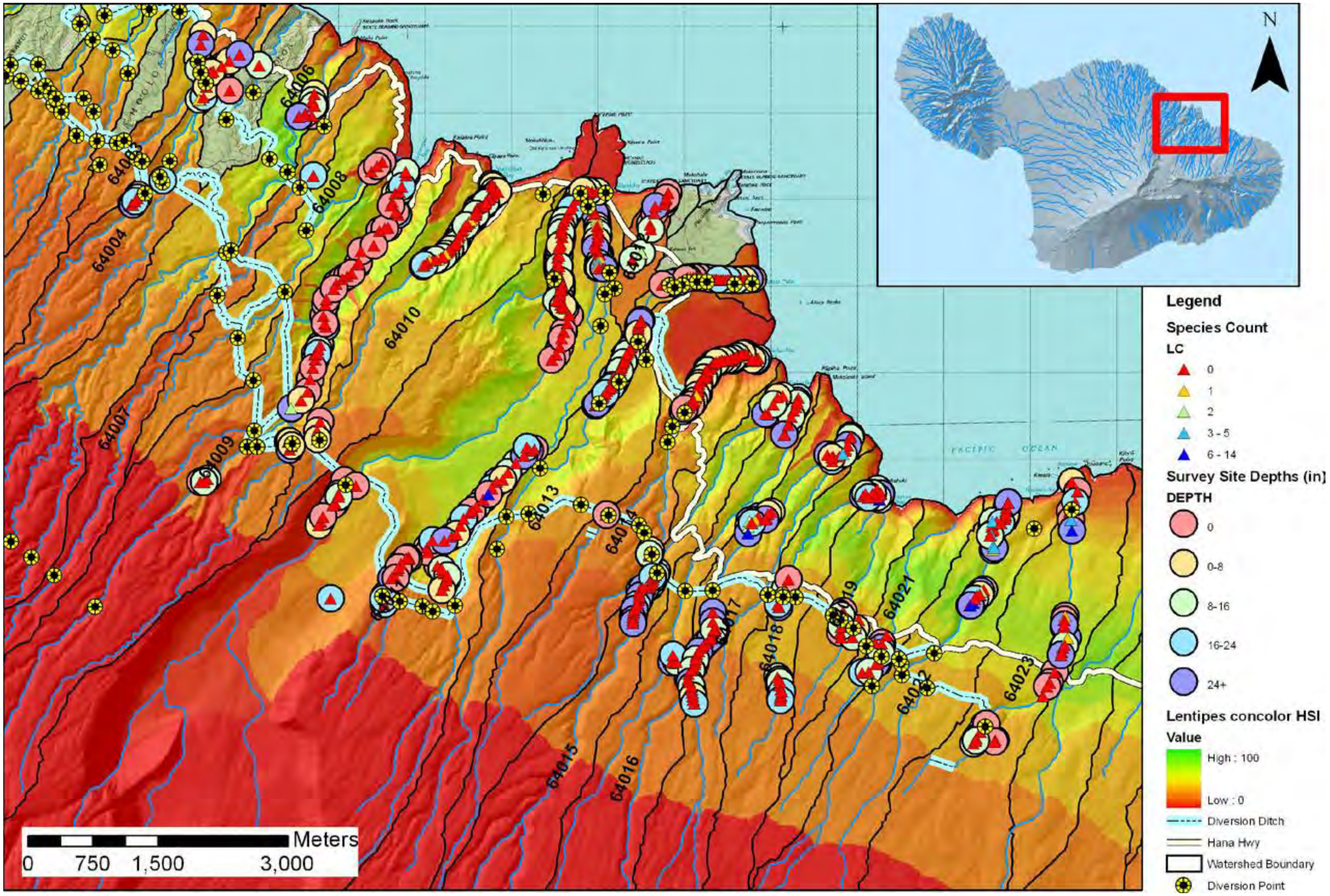


Figure 58. Predicted Habitat Suitability Index (HSI) for *Lentipes concolor*. Map includes survey site depths and count of *Lentipes concolor* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

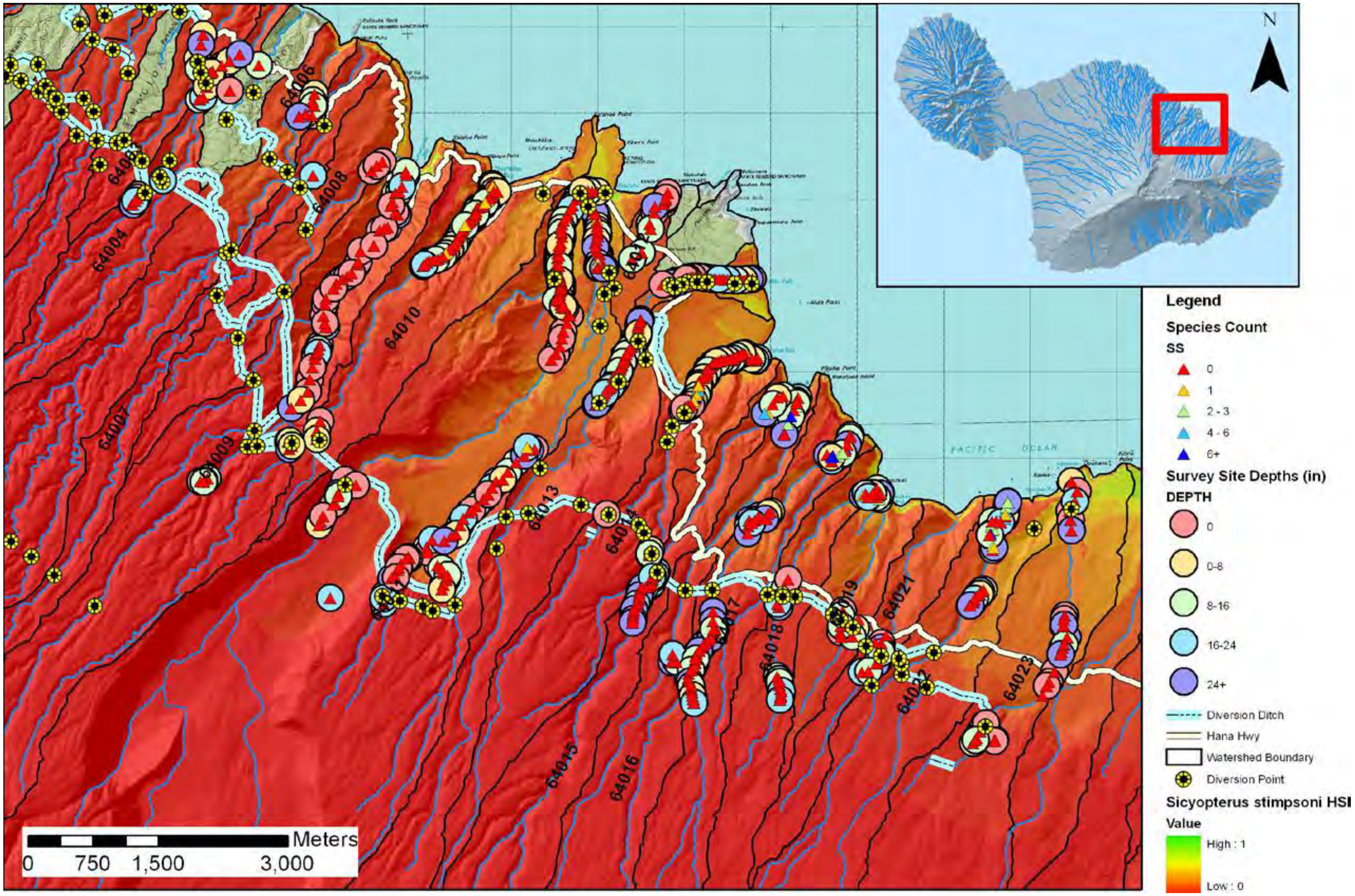


Figure 59. Predicted Habitat Suitability Index (HSI) for *Sicyopterus stimpsoni*. Map includes survey site depths and count of *Sicyopterus stimpsoni* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

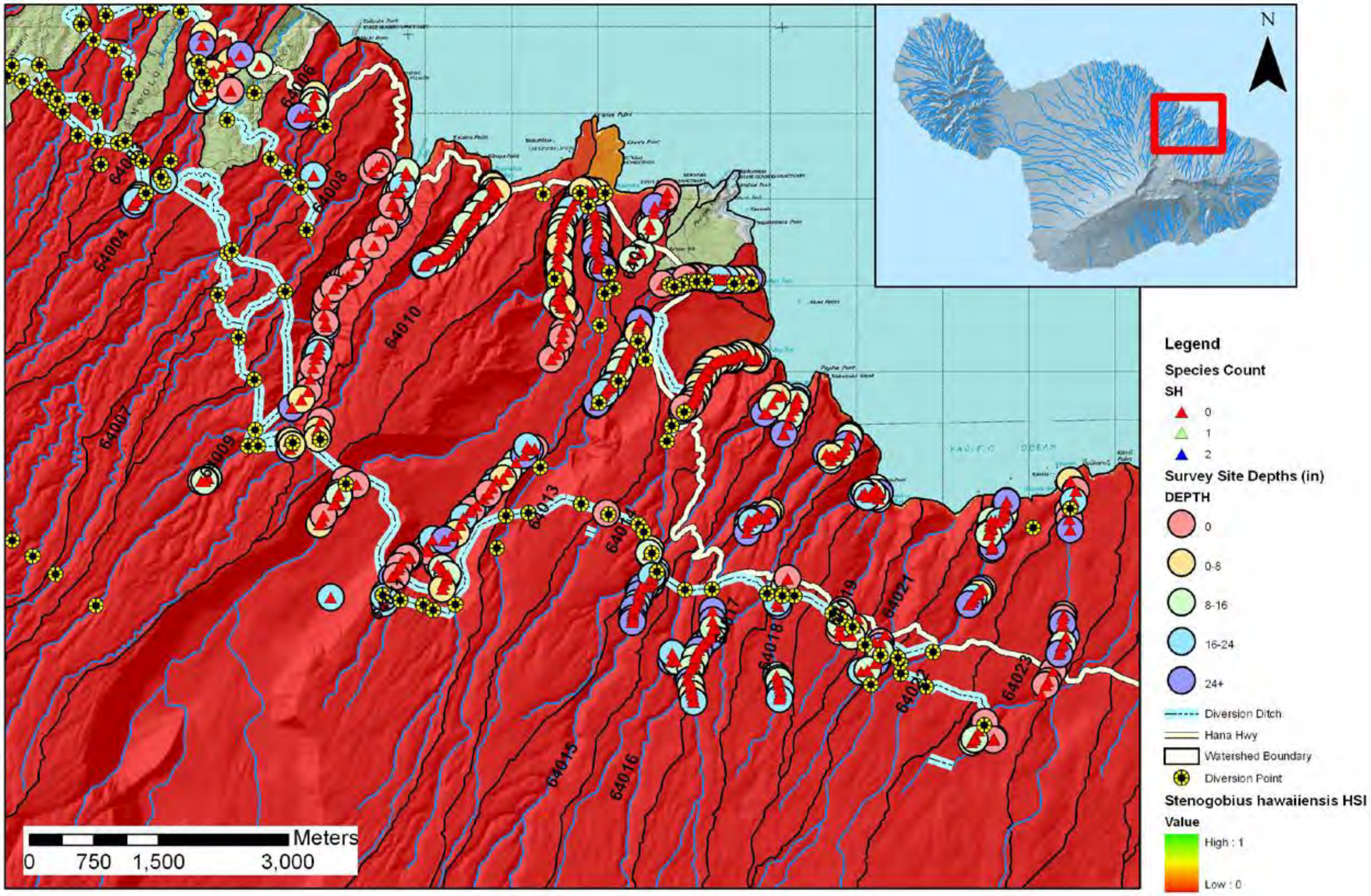


Figure 60. Predicted Habitat Suitability Index (HSI) for *Stenogobius hawaiiensis*. Map includes survey site depths and count of *Stenogobius hawaiiensis* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

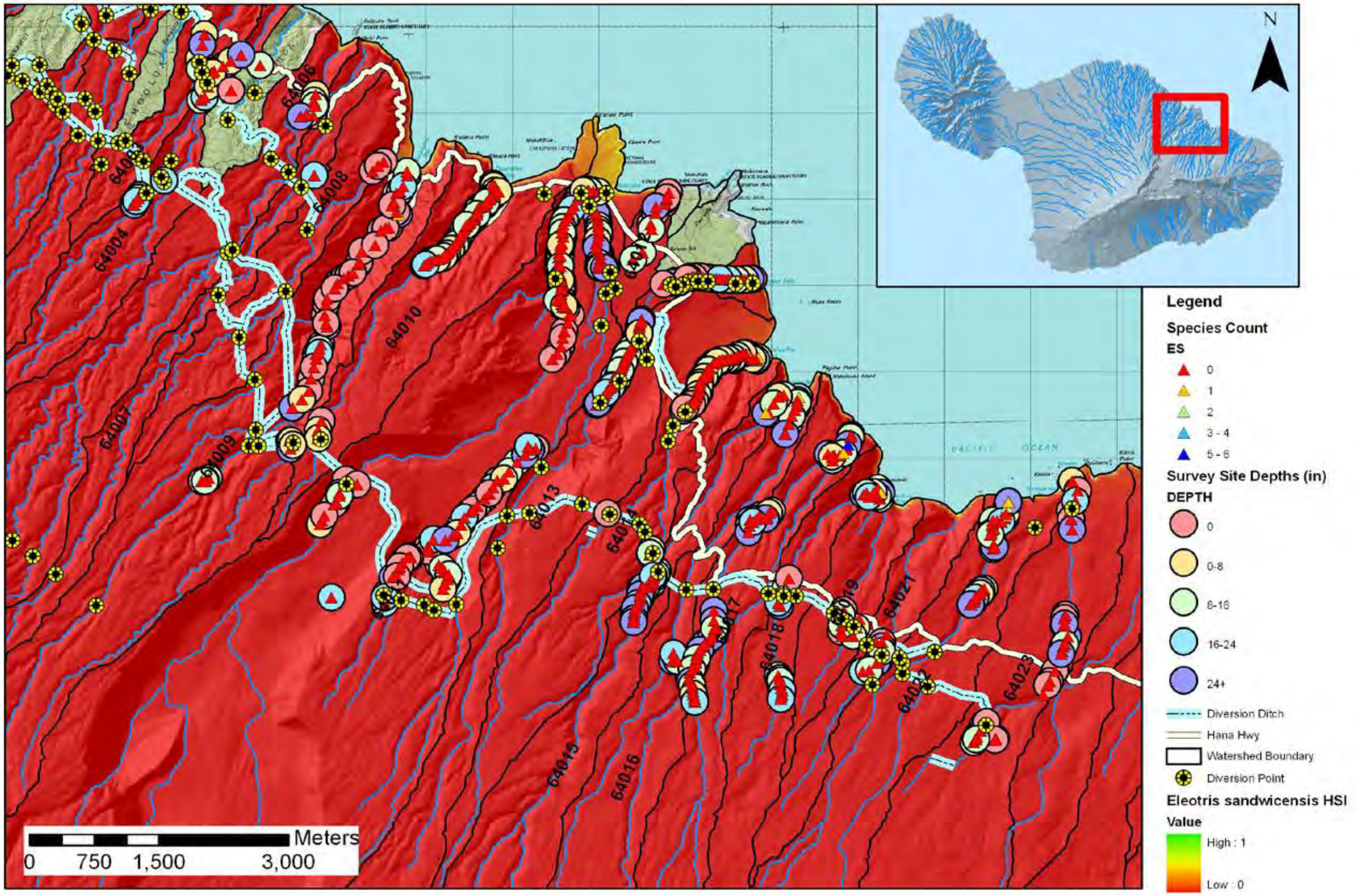


Figure 61. Predicted Habitat Suitability Index (HSI) for *Eleotris sandwicensis.* Map includes survey site depths and count of *Eleotris sandwicensis* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

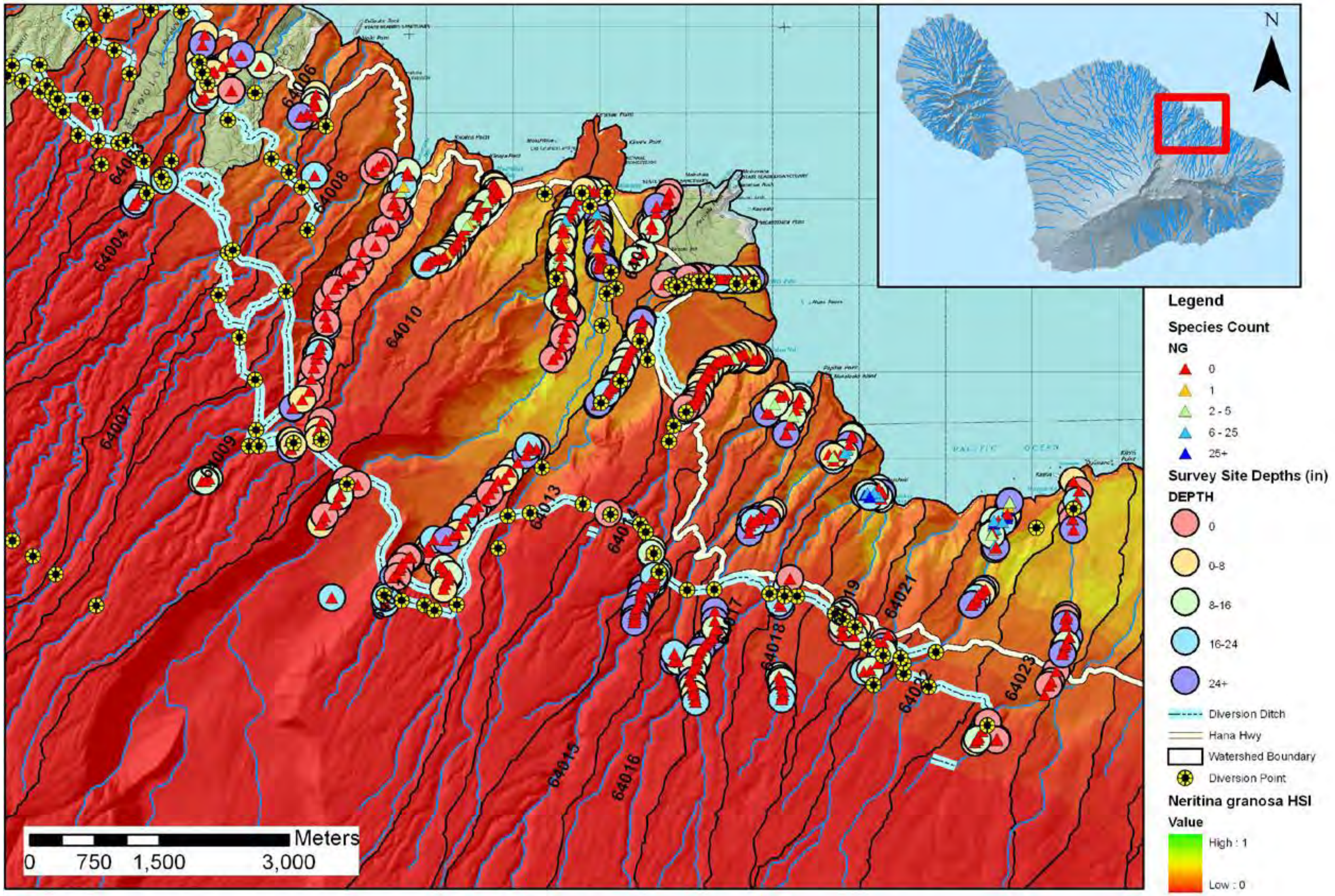


Figure 62. Predicted Habitat Suitability Index (HSI) for *Neritina granosa*. Map includes survey site depths and count of *Neritina granosa* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

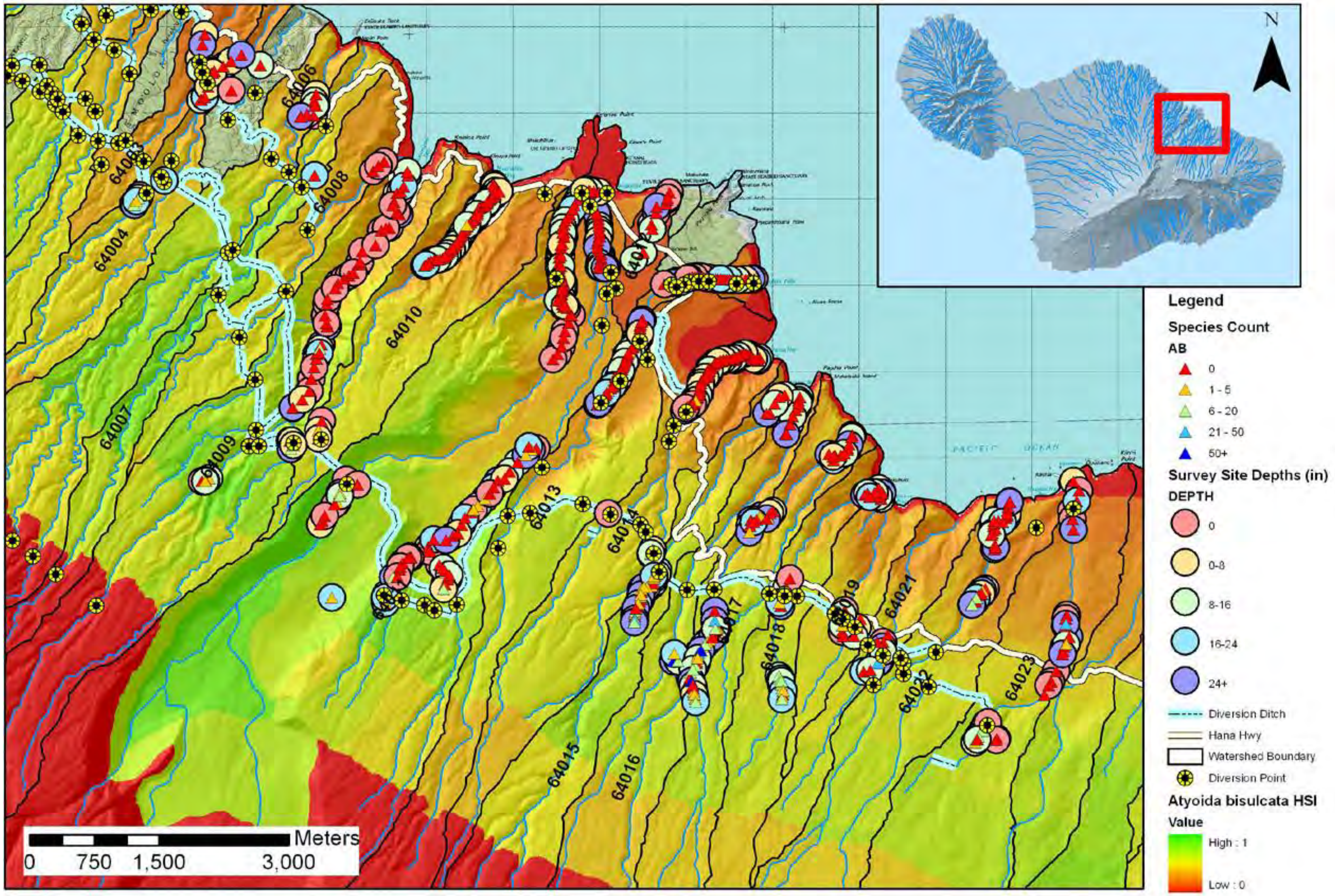


Figure 63. Predicted Habitat Suitability Index (HSI) for *Atyoida bisulcata.* Map includes survey site depths and count of *Atyoida bisulcata* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

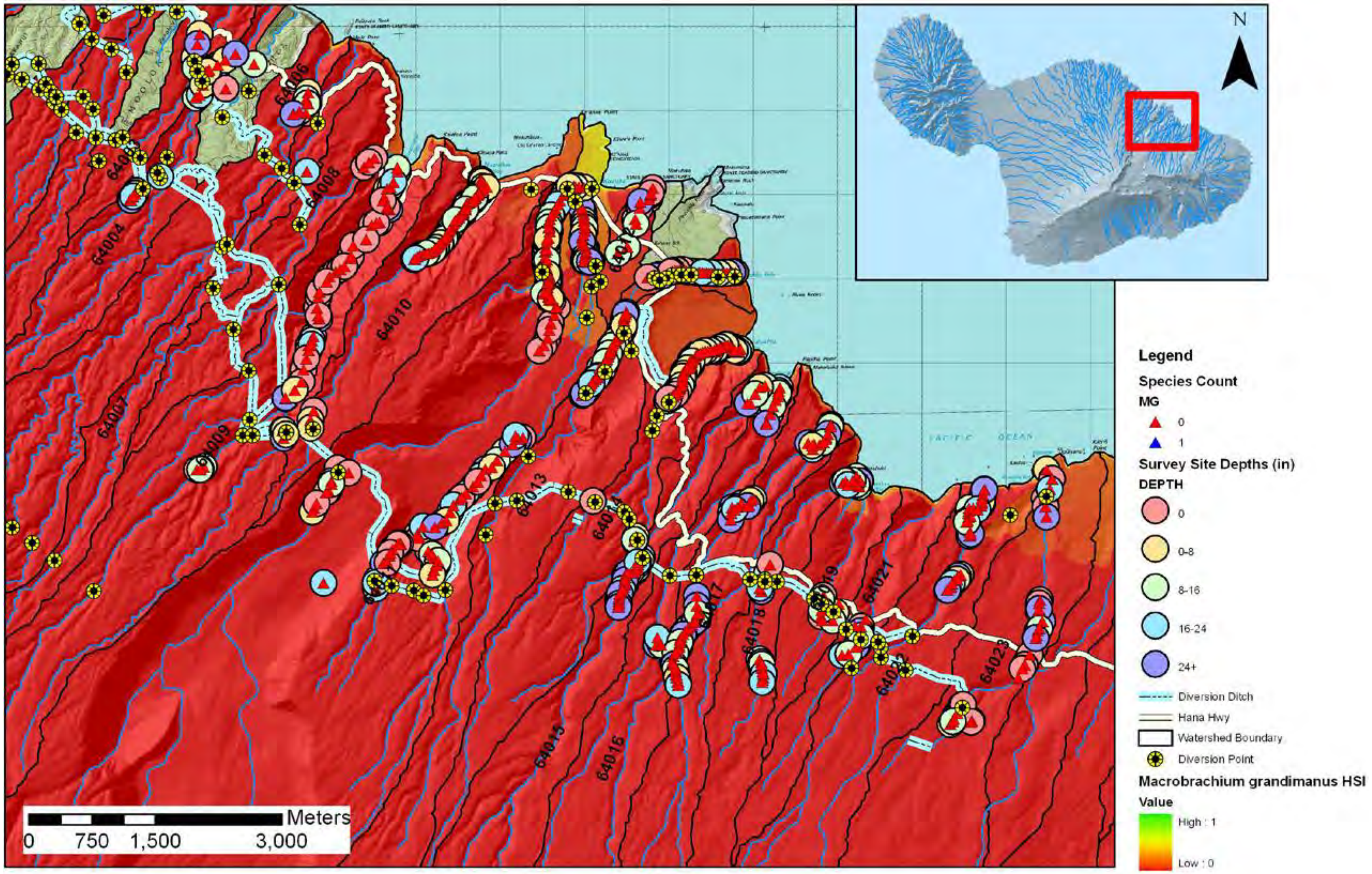


Figure 64. Predicted Habitat Suitability Index (HSI) for *Macrobrachium grandimanus*. Map includes survey site depths and count of *Macrobrachium grandimanus* observed at each site. Diversions, diversion ditches, Hana Highway, and watershed boundaries and codes are included for reference.

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
Haipuaʻena	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
Nuaʻailua	64010	1,711	1,711	1,506	1,465	246	15	14.4%	15	0.0%	14
ʻŌhiʻa	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
Kopiliʻula	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
Kapāʻula 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
Haipuaʻena	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
Nuaʻailua	64010	13.7	13.7	13.7	13.7	0.0	11	0.0%	11	0.0%	11
ʻŌhiʻa	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
Kopiliʻula	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
Kapāʻula 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
Haipua‘ena	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
Nua‘ailua	64010	801	801	801	801	0	15	0.0%	15	0.0%	14
‘Ōhi‘a	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
Kopili‘ula	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
Kapā‘ula 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
Haipuaʻena	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
Nuaʻailua	64010	646	646	422	378	268	13	41.6%	15	0.0%	14
ʻŌhiʻa	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
Kopiliʻula	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
Kapāʻula 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%
Kopili‘ula	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%
Haipua‘ena	Between D2 – D3	640073	barrier	2,009	10	3.0%	49.9%
Kopili‘ula	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%
Kapā‘ula 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%
Haipua‘ena	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%
Haipua‘ena	Between D3 – D4	640074	barrier	757	33	1.1%	94.7%
Haipua‘ena	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%

Literature Cited:

DAR Reports on the East Maui streams, referenced as (Report on *Name of Stream*, 2009)

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, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 36 p.

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 Waikamoi Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 44 p.

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 Puohokamoa Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 32 p.

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 Punalau Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 32 p.

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 Honomanū Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 64 p.

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 Nuaʻailua Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 56 p.

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 ʻŌhiʻa Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 38 p.

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 West Wailua Iki Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 57 p.

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 East Wailua Iki Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

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 Kopiliʻula Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

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 Waiohue Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

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 Paakea Gulch, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

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 Kapāʻula Gulch, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 34 p.

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 Hanawī Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 46 p.

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 Makapipi Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

Additional references:

Bell, K. N. I. 2007. Opportunities in stream drift: methods, goby larval types, temporal cycles, in-situ mortality estimation, and conservation implications. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3: 35-62.

Burky A.J., Benbow M.E.and C.M. Way. 1999. Amphidromous Hawaiian Gobies: Diurnal patterns of metabolism and upstream migration. Bull NABS 16(1):213. ABSTRACT

Devick, W. S. 2007. Establishment of an integrated instream flow program in Hawai'i consistent with Public Trust Doctrine. In: Biology of Hawaiian Streams and Estuaries, N. L.

Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:327-330.

Division of Aquatic Resources. 2009. Aquatic Surveys Database: http://www.hawaii.gov/dlnr/dar/streams/stream_data.htm

Frissell, C.A.; W.J. Liss, W.J.; Warren, C.E.; Hurley, M.C. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10: 199-214.

Fitzsimons, J. M., M.G. McRae, and R. T. Nishimoto. 2007. Behavioral ecology of indigenous stream fishes in Hawai‘i. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:11-22.

Fitzsimons, J. M. and R. T. Nishimoto. 2007. Introduction. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:11-22.

Gingerich, S.B. 2005. Median and Low Flow Characteristics for Stream under Natural and Diverted Conditions, Northeast Maui, Hawaii: Honolulu, HI. U.S. Geological Survey Scientific Investigations Report 2004-5262, 72 p.

Gingerich, S.B. and Wolff, R.H. 2005. Effects of surface-water diversions on habitat availability for native macrofauna, northeast Maui, Hawaii: U.S. Geological Survey Scientific Investigations Report 2005-5213, 93 p.

Hau, S. 2007. Hīhīwai (*Neritina granosa* Sowerby) recruitment in ‘Īao and Honomanū Streams on the Island of Maui, Hawai‘i. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:171-182.

Higashi, G. R., and R. T. Nishimoto. 2007. The point quadrat method: a rapid assessment of Hawaiian streams. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:305-314.

Iguchi, K. 2007. Early seaward drift of gobies in Japan. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:75-86.

Iguchi, K., and N. Mizuno. 1999. Early starvation limits survival in amphidromous fishes. Journal of Fish Biology 54:705–712.

Kido, M. H., and D.E. Heacock. 1992. The spawning ecology of ‘o‘opu nakea (*Awaous stamineus*) in Wainiha River and other selected north shore Kaua‘i rivers, p. 142–157. In: W.S. Devick (ed.), New directions in research, management, and conservation of

Hawaiian freshwater stream ecosystems. Proceedings of the 1990 Symposium on Freshwater Stream Biology and Management, Hawaii Division of Aquatic Resources.

Kinzie, R. A., III, J. Ford, A. R. Yuen, and S. J. L. Chow. 1986. Habitat modeling of Hawaiian streams. Water Resources Center Technical Report 171, University of Hawai'i, Honolulu.

Kuamo'o, D. G. K., G. R. Higashi & J. E. Parham. 2007. Structure of the Division of Aquatic Resources Survey Database and use with a Geographic Information System. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis & J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3: 315-322.

Levin, S.A. 1992. The Problem of Pattern and Scale in Ecology: The Robert H. MacArthur Award Lecture. Ecology 73(6) 1943-1967.

Lindstrom, D. P. 1998. Reproduction, early development, and larval transport dynamics of amphidromous Hawaiian gobies. Ph.D. dissertation (Zoology), University of Hawai'i. 131 pp.

McDowall, R. M. 2007. Hawaiian stream fishes: the role of amphidromy in history, ecology, and conservation biology. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:3-10.

McRae, M. G. 2007. The potential for source – sink population dynamics in Hawaii's amphidromous fishes. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:87-98.

Meadows, D., A. L. Kane, C. Mitchell, and C. Ogura. 2005. Technical Report X. Hawaiʻi Statewide Aquatic Wildlife Conservation Strategy. Pacific Cooperative Studies Unit. University of Hawaiʻi at Mānoa. Honolulu.

Murphy, C. A., and J. H. Cowan, Jr. 2007. Production, marine larval retention or dispersal, and recruitment of amphidromous Hawaiian gobioids: issues and implications. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:63-74.

Nishimoto, R. T., and D. G. K. Kuamoʻo. 1997. Recruitment of goby postlarvae into Hakalau Stream, Hawaiʻi Island. Micronesica 30:41–49.

O'Neill, R.V., D.L. DeAngelis, J.B. Waide and T.F.H. Allen. 1986. A Hierarchical Concept of Ecosystems. Monographs in Population Biology 23. Princeton University Press. Princeton, NJ. 253p.

Parham, J. E. 2002. Spatial models of Hawaiian streams and stream fish habitats. Ph.D. dissertation, Louisiana State University, Baton Rouge.

Parham, J. E. 2008. Development of a database modeling tool to predict aquatic species distributions within Hawaiian streams. Division of Aquatic Resources, DLNR, State of Hawaii. 56 p.

Parham, J. E., G. R. Higashi, E. K. Lapp, D. G. K. Kuamo'o, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick. 2008. Atlas of Hawaiian Watersheds and Their Aquatic Resources. Island of Maui. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 866 p.

Sale, P.F. 1978. Coexistence of coral reef fishes – a lottery for living space. Env. Biol. Fish. Vol. 3, No. 1, pp. 85-102.

Schoenfuss, H. L., and R. W. Blob. 2007. The importance of functional morphology for fishery conservation and management: applications to Hawaiian amphidromous fishes. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis and J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3:125-142.

U.S. Fish and Wildlife Service (USFWS). 1980a. Habitat as the Basis for Environmental Assessment (101 ESM). U.S. Fish and Wildlife Service, Washington, DC.

U.S. Fish and Wildlife Service (USFWS). 1980b. Habitat evaluation procedure (HEP) Manual (102 ESM). U.S. Fish and Wildlife Service, Washington, DC.

U.S. Fish and Wildlife Service (USFWS). 1981. Standards for the development of habitat suitability index models (103 ESM). U.S. Fish and Wildlife Service, Washington, DC.

Appendix B

Letter of December 15, 2009

LINDA LINGLE
GOVERNOR OF HAWAII

LAURA H. THIELEN
CHAIRPERSON
BOARD OF LAND AND NATURAL RESOURCES
COMMISSION ON WATER RESOURCE MANAGEMEN

RUSSELL Y. TSUJI
FIRST DEPUTY

KEN C. KAWAHARA
DEPUTY DIRECTOR - WATER

AQUATIC RESOURCES
BOATING AND OCEAN RECREATION
BUREAU OF CONVEYANCES
COMMISSION ON WATER RESOURCE MANAGEMEN
CONSERVATION AND COASTAL LANDS
CONSERVATION AND RESOURCES ENFORCEMENT
ENGINEERING
FORESTRY AND WILDLIFE
HISTORIC PRESERVATION
KAHOOLAWE ISLAND RESERVE COMMISSION
LAND
STATE PARKS

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF AQUATIC RESOURCES
1151 PUNCHBOWL STREET, ROOM 330
HONOLULU, HAWAII 96813

December 15, 2009

Commission on Water Resource Management
Kalanimoku Building
1151 Punchbowl Street, Room 227
Honolulu, Hawaii 96813

Dear Commission members:

On May 24, 2001, the Native Hawaiian Legal Corporation (NHLC) filed a Petition to Amend the Interim Instream Flow Standards (IIFS) for 27 streams in East Maui on behalf of resident taro farmers. Since the acceptance of the petitions in July 2001, the Commission on Water Resource Management (CWRM) has been focused on gathering information for the 27 petitioned streams. Shortly thereafter, NHLC and CWRM staff reached an agreement that efforts would focus on 8 of the 27 petitioned streams: Honopou, Hanehoi, Huelo, Waiokamilo, Kualani, Pi‘ina‘au, Palauhulu, and Wailua Nui Streams. DAR provided input to aid CWRM on its decision for the first eight streams. Subsequently, CWRM began deliberations for setting IIFS for the additional petitioned 19 streams. In this letter, the Division of Aquatic Resources provides recommendations focused on these additional 19 streams.

The Division of Aquatic Resources (DAR) is responsible for the protection and management of living aquatic resources in the waters of Hawaii. The DAR realizes that the Commission on Water Resource Management (CWRM) has the responsibility of balancing the current and future value of multiple uses of water when rendering its decisions on specific Instream Flow Standards. By contrast, the DAR's recommendations below focus only on the requirements of the native aquatic biota that fall within the scope of our authority, and do not consider additional instream or offstream uses of stream water. This letter provides the DAR's recommendations for actions that support restoration of native species habitat, migratory pathways for upstream recruiting individuals and downstream drifting larvae, and overall population structure for eight native fish and macroinvertebrate species inhabiting East Maui streams.

The DAR's recommendations are based on several lines of evidence. First, DAR biologists and technicians spent considerable time and effort surveying habitat and animal populations in these streams. Second, the DAR compared the results of the stream surveys with estimates of expected native species occurrence by utilizing the Hawaiian Stream Habitat Evaluation Procedure (HSHEP) analytic model, the results of which for the 19 streams in question (Parham et al., 2009) were provided to CWRM staff on November 20, 2009. Finally, the DAR used available information and the extensive experience of its staff in determining the final list of actions needed to support restoration of native species in these 19 streams. A list of supporting documentation for these recommendations is provided at the end of this letter.

Water diversion structures have two main effects on native amphidromous animals. First, the amount of habitat below a diversion is decreased or eliminated with the removal of water. Second, native animals are entrained by the diversion structure during their upstream and downstream migrations and eliminated from the population. The DAR recommends that stream diversions be modified to allow adequate water to pass downstream and to decrease entrainment. By following this strategy, maximum gains to native species habitat can be realized from a minimal amount of management action. Additionally, as a result native amphidromous animal migration between the ocean and the stream in each life cycle, priority is placed on restoring stream habitat and connectivity in an upstream direction, with actions undertaken at the lowermost diversion first.

While the return of 100% of the diverted water and elimination of diversion structures would be the most desirable IIFS for protection and management of native stream animals, the DAR recognizes that this position is not compatible with the on-going needs for water by the people of Maui. **Although the DAR understands that some water will continue to be diverted from East Maui streams to meet such needs, the DAR feels that the continuance of the status quo for all but one of the stream diversions, as proposed in the current CWRM petition, is unacceptable and therefore has provided recommendations for additional restoration actions.** Our recommendations represent essential actions that will greatly enhance native species habitat, connectivity, and overall population structure and viability. In no case are additional diversions of stream water recommended.

In the following description of essential actions, recommendations are ordered based on their expected increase in overall habitat for the eight native species of concern. Also, the reported amount of Habitat Units (quantified as 10 m^2 cells; see Parham et al., 2009) restored may be larger than the total length of restored stream as multiple species may inhabit the same area. The amount of water to be returned at any recommended location would be the amount necessary to achieve 90% habitat restoration based on relationships between habitat and stream flow developed by the USGS for East Maui streams. Modification of diversions to decrease entrainment and increase passage may be required in addition to the modifications to provide sufficient downstream flow.

Essential Management Recommendations:

1. Honomanū Stream – DAR recommends modification of the Ko'olau Ditch diversion structure to provide for suitable habitat downstream and animal passage

at the diversion site. This action would restore approximately 11.6 km of Habitat Units for native species. Currently, much of the lower end of Honomanū Stream is dry, and this action would restore a large amount of stream habitat for a many native species. Recruitment of native species has been observed at the stream mouth, but the dry streambed above restricts upstream movement. Rewatering of the lower stream section would greatly improve animal migration and increase populations of native animals in this catchment. Additionally, Honomanū Stream empties into a bay where the restoration of stream flow would benefit native estuarine animals, expand nursery habitat for marine species, and improve larval dispersal for various native stream animals.

2. Puohokamoa Stream - DAR recommends modification of the Manuel Luis Ditch and Wailoa Ditch diversion structures to provide for suitable instream habitat and to allow animal passage at both diversion sites. These two actions would restore approximately 7.6 km of Habitat Units for native species. Puohokamoa Stream has additional diversions upstream of the Wailoa Ditch, but modifications of these diversions would provide less ecological benefit. Native aquatic species were observed in this stream, and improved instream habitat and connectivity as proposed would greatly enhance the overall ecological viability of this stream.

3. Waikamoi Stream - DAR recommends modification of the Manuel Luis Ditch and Wailoa Ditch diversion structures to increase suitable instream habitat and allow animal passage at both diversion sites. These two actions would restore approximately 5.8 km of Habitat Units for native species. Waikamoi Stream has additional diversions upstream of the Wailoa Ditch, but modifications of these diversions would provide less benefit to native species and are not proposed herein.

4. Kopili‘ula Stream - DAR recommends modification of the Ko‘olau Ditch diversion structures on both the main channel and on the Pua‘aka‘a tributary to provide for suitable habitat downstream and animal passage at the diversion sites. These actions would restore approximately 5.1 km of Habitat Units for native species, which were observed in this stream. Additional habitat provided below the diversion and increased connectivity of habitats above and below the diversion would further expand native animal habitat and improve viability of populations.

5. East Wailua Iki - DAR recommends modification of the Ko‘olau Ditch diversion structure to provide for suitable habitat downstream and to increase upstream migration of native animals. This action would restore approximately 4.4 km of Habitat Units for native species. Restoration of flow would further enhance the overall stream productivity.

6. West Wailua Iki - DAR recommends modification of the Ko‘olau Ditch diversion structure to provide for suitable habitat downstream and animal passage at the diversion site. This action would restore approximately 4.0 km of Habitat Units

for native species. Flow restoration will provide additional habitat in the lower, middle, and upper reaches.

7. Makapipi - DAR recommends modification of the Ko'olau Ditch diversion structure to provide for suitable habitat downstream of the diversion, and animal passage at the diversion site. This action would restore approximately 3.8 km of Habitat Units for native species.

8. Hanawī Stream - DAR recommends modification of the Ko'olau Ditch diversion structure to provide for animal passage at the diversion site. This action would link the lower section of the stream with the upper section, and would restore approximately 3.5 km of Habitat Units for native species. No restoration of water is required except that necessary to provide a wetted pathway past the diversion structure. The lower section of Hanawī Stream is highly productive habitat for native stream animals and has large springs which provide flow and habitat even during drought periods. Overall, Hanawī Stream is an outstanding stream with a healthy and diverse population of native species, and therefore reconnecting the upper and lower sections would protect and enhance the ecological integrity of this particularly valuable stream.

The above recommendations propose flow restoration on only 8 of the 19 streams under consideration, but would result in restoration of 45.8 km of native species Habitat Units out of a total of the 67.3 km of Habitat Units currently lost as a result of the major ditch diversions. They therefore represent a significant return of ecological function based on a modest investment in flow restoration, and we urge their favorable consideration.

Sincerely,

DAN A. POLHEMUS, Administrator
Division of Aquatic Resources

References:

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, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 36 p.

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 Waikamoi Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 44 p.

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 Puohokamoa Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 32 p.

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 Punalau Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 32 p.

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 Honomanū Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 64 p.

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 Nuaʻailua Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 56 p.

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 ʻŌhiʻa Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 38 p.

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 West Wailua Iki Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 57 p.

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 East Wailua Iki Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

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 Kopiliʻula Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

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 Waiohue Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

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 Paakea Gulch, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

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 Kapāʻula Gulch, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 34 p.

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 Hanawī Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 46 p.

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 Makapipi Stream, Maui, Hawaiʻi. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

Parham, J. E. 2008. Development of a database modeling tool to predict aquatic species distributions within Hawaiian streams. Division of Aquatic Resources, DLNR, State of Hawaii. 56 p.

Parham, J. E., G. R. Higashi, E. K. Lapp, D. G. K. Kuamoʻo, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick. 2008. Atlas of Hawaiian Watersheds and Their Aquatic Resources. Island of Maui. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 866 p.

Parham, J.E., G.R. Higashi, R.T. Nishimoto, S. Hau, D.G.K. Kuamoʻo, L.K. Nishiura, T.S. Sakihara, T.E. Shimoda and T.T. Shindo. 2009. The Use of Hawaiian Stream Habitat Evaluation Procedure to Provide Biological Resource Assessment in Support of Instream Flow Standards for East Maui Streams. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 104 p.

Appendix C

Letter of April 1, 2010

LINDA LINGLE
GOVERNOR OF HAWAII

LAURA H. THIELEN
CHAIRPERSON
BOARD OF LAND AND NATURAL RESOURCES
COMMISSION ON WATER RESOURCE MANAGEMENT

RUSSELL Y. TSUJI
FIRST DEPUTY

KEN C. KAWAHARA
DEPUTY DIRECTOR - WATER

AQUATIC RESOURCES
BOATING AND OCEAN RECREATION
BUREAU OF CONVEYANCES
COMMISSION ON WATER RESOURCE MANAGEMENT
CONSERVATION AND COASTAL LANDS
CONSERVATION AND RESOURCES ENFORCEMENT
ENGINEERING
FORESTRY AND WILDLIFE
HISTORIC PRESERVATION
KAHOOLAWE ISLAND RESERVE COMMISSION
LAND
STATE PARKS

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF AQUATIC RESOURCES
1151 PUNCHBOWL STREET, ROOM 330
HONOLULU, HAWAII 96813

April 1, 2010

Dear Ken Kawahara:

As the result of the December 19, 2009 ruling from the Water Commission to further document the stream flows required to protect native animal species in the East Maui streams, DAR engaged in a series of meetings with CWRM, USGS, Bishop Museum, and HC&S in to attempt to provide clear information in a useable format that will facilitate agreement on the appropriate restoration flows. This document provides a narrative that is intended to accompany the report cards and spreadsheets which show the information used in the latest ranking of the restoration potential for East Maui Streams.

In a general sense, DAR supports the following positions regarding restoration efforts in East Maui Streams.

- Minimum viable habitat flow (H_{min}) for the maintenance of suitable instream habitat is defined as 64% of Median Base Flow (BFQ_{50})(also defined as H90 by USGS studies). DAR expects that these flows will provide suitable conditions for growth, reproduction, and recruitment of native stream animals.
- Minimum viable connectivity flow (C_{min}) for the maintenance of a wetted pathway between the ocean and stream habitats is defined as 20% BFQ_{50}. These flows are expected to allow the animals to move among habitats. These flows are considered by DAR to be too low to expect suitable longterm growth and reproduction of native stream animals
- Seasonally adjusted flows, H_{min} during the wet season and C_{min} during the dry season may mimic the natural flow variability observed in Hawaiian streams and support most ecological functions required by the stream animals.
- Avoidance of entrainment at diversion locations is important to maximize populations of native stream animals while minimizing the negative impacts from stream diversions.
- Restoration of stream flow should reflect the water budget of the individual stream catchment. The use of trans-basin water diversions from ditches to restore stream sections should be avoided where at all possible.
- Co-mingling of stream and ditch flows should be avoided where at all possible to limit the potential spread of invasive aquatic species.
- Restoration of streams should be spread out in a geographic sense. This will provide a greater protection against localized habitat disruptions, a wider benefit to estuarine and nearshore marine species, and result in more comprehensive ecosystem function across the entire East Maui sector.

Based on the above philosophical management framework, DAR used several criteria to reassess the streams recommended for restoration in East Maui. First the amount of habitat units currently lost to diversion was considered. Greater amounts of habitat restored were considered a positive attribute. Second, seasonality (wet versus dry seasons) was considered by setting minimum connectivity flows during the dry season and minimum habitat flow during the wet season. Third, issues related to losing reaches were considered. Both Honomanū and Makapipi Streams were eliminated for consideration in consultation with CWRM, USGS, and Bishop Museum on the basis of losing reach concerns. Fourth, we considered restoration of the stream systems most biologically impacted by dewatering, assessed on the basis of missing faunal components. Fifth, the number and difficulty of modifications for diversions was considered. Our current assessment of this factor would be improved through consultation with HC&S, CWRM, and other experienced engineers and fish passage experts. Sixth, we also considered the efficient use of water in terms of the rate of Habitat Units restored per *cfs* of water returned. Seventh, we evaluated whether the restoration of stream flow along a given stream segment involved the co-mingling of stream and ditch water. Finally, we attempted to geographically distribute the streams proposed for restoration across the entire East Maui ecosystem.

The attached information is a synopsis of our recommendations for stream flow restoration on select East Maui streams and is based on recalculation of the Hawaii Stream Habitat Evaluation Procedure (HSHEP) model to include analysis of estimates for minimum connectivity and habitat flow for each stream segment to address seasonality. The recommendation for each stream and its diversions are included on the report card for each stream.

Additional information on the other 10 East Maui Streams are not included as DAR does not recommend habitat restoration actions in these streams as the habitat gains would be minimal and suggest to maintain them as status quo.

Note in the photographs and accompanying text that references of left and right bank are based on the orientation of looking upstream. We look forward to working with all parties to reclaim ecological habitat for native stream animals, and to provide connectivity for the inland return of young, and the downstream exit of new hatches into the nearshore estuarine nursery areas along this coastline. We believe that adoption of our recommendations would provide a significant return of ecological function based on a modest investment in flow restoration, and will continue to refine them in consultation with all parties.

Sincerely,

ROBERT T. NISHIMOTO, Environmental Program Manager
Division of Aquatic Resources

Attachments

References:

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, 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.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Waikamoi Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 44 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Puohokamoa Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 32 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Punalau Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 32 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Honomanū Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 64 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Nua'ailua Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 56 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on 'Ōhi'a Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 38 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on West Wailua Iki Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 57 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on East Wailua Iki Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Kopili'ula Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Waiohue Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Paakea Gulch, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Kapā'ula Gulch, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 34 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Hanawī Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 46 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo'o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Makapipi Stream, Maui, Hawai'i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

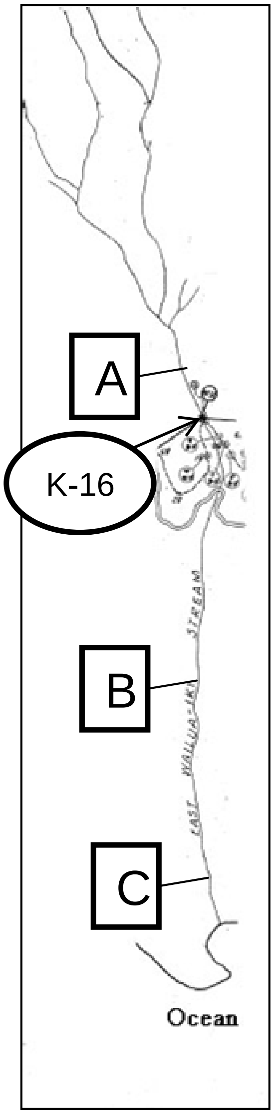
Parham, J. E. 2008. Development of a database modeling tool to predict aquatic species distributions within Hawaiian streams. Division of Aquatic Resources, DLNR, State of Hawaii. 56 p.

Parham, J. E., G. R. Higashi, E. K. Lapp, D. G. K. Kuamo'o, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick. 2008. Atlas of Hawaiian Watersheds and Their Aquatic Resources. Island of Maui. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 866 p.

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

East Wailua Iki Stream

DAR Priority Rank: 1

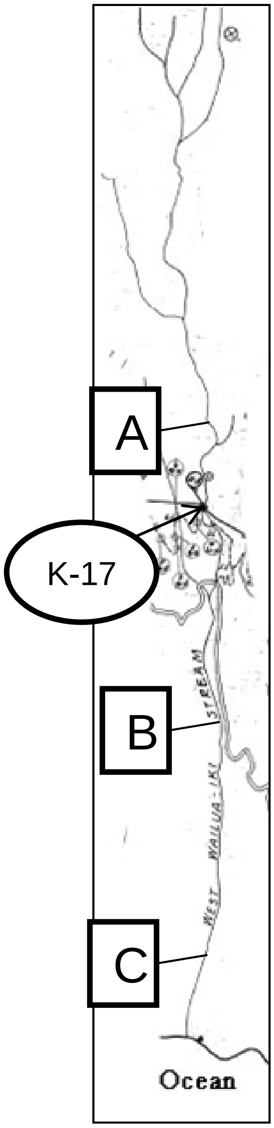


Area	Natural BFQ_{50} (cfs)	Diverted BFQ_{50} (cfs)	Wet Season H_{min} (cfs)	Dry Season C_{min} (cfs)	Habitat Units Restored (m)
A	5.8	5.8	No change	No change	951
Diversion K-16				Difficulty of diversion restoration: **Simple (1)** Provide passage in left bypass channel	
B	6.8	1.0	4.5 (+3.2)	1.4 (+0.2)	1,452
C	7.2	1.5			
Total Returned			3.2	0.2	2,402

DAR Recommendations - East Wailua Iki has great potential for restoration as increased stream flow would restore extensive habitats lost to flow diversion and the modifications needed for the diversion are limited. DAR recommends the release of 3.2 cfs of water during the wet season to provide for minimum habitat flows and 0.2 cfs of water during the dry season to provide connectivity. Modification would involve a v-notch on the upstream dam wall on the left bank on the diversion structure (K-16 Koʻolau Ditch). This would allow passage up and down stream without entrainment of native animals to the gravel basin and ditch system. These restoration actions would provide over 2.4 km of additional native animal habitat.

West Wailua Iki Stream

DAR Priority Rank: 2

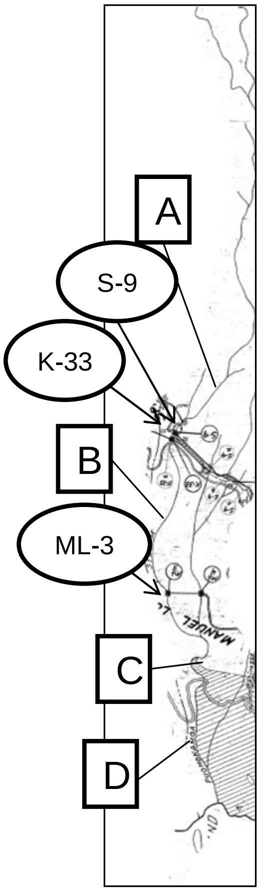


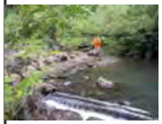
Area	Natural BFQ_{50} (cfs)	Diverted BFQ_{50} (cfs)	Wet Season H_{min} (cfs)	Dry Season C_{min} (cfs)	Habitat Units Restored (m)
A	6.0	6.0	No change	No change	886
Diversion K-17				Difficulty of diversion restoration: **Simple (1)** Provide passage on right side of channel	
B	6.8	0.8	4.5 (+3.5)	1.4 (+0.4)	1,331
C	7.2	1.2			
Total Returned			3.5	0.4	2,218

DAR Recommendations - West Wailua Iki has very good restoration potential as increased stream flow would restore extensive habitats lost to flow diversion and the modifications needed for the diversion are straightforward. DAR recommends the release of 3.5 cfs of water during the wet season to provide for minimum habitat flows and 0.4 cfs of water during the dry season to provide connectivity. Modifications to the diversion structure (K-17 Ko‘olau Ditch) would involve a v-notch on the dam wall below the waterfall pool away from the ditch on the right bank. These restoration actions would provide over 2.2 km of additional native animal habitat.

Puohokamoa Stream

DAR Priority Rank: 3

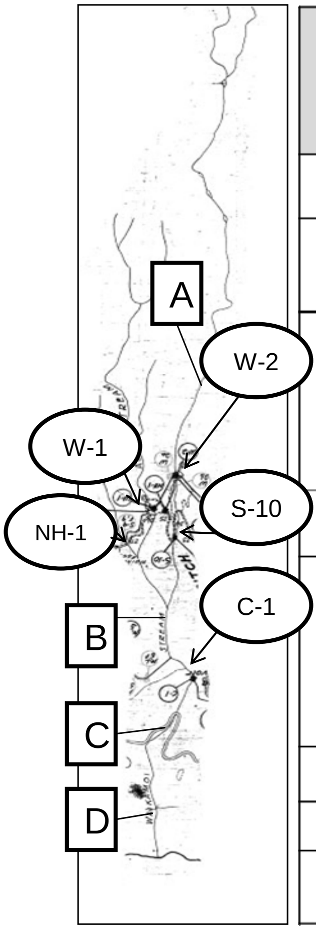


Area	Natural BFQ_{50} (cfs)	Diverted BFQ_{50} (cfs)	Wet Season H_{min} (cfs)	Dry Season C_{min} (cfs)	Habitat Units Restored (m)
A	6.4	6.4	No change	No change	668
Diversions K-33 & S-9				Difficulty of diversion restoration: **Moderate (2)** Two diversion each simple (1)	
B	8.4	2.0	5.4 (+3.4)	2.1 (+0.1)	635
Diversion ML-3				Difficulty of diversion restoration: **Simple (1)** Need to pass diversion	
C	12	1.1	7.4 (+2.0)	2.3 (+0.2)	1,498
D	11	2.1			
Total Returned			5.4	0.3	2,801

DAR recommendations - Puohokamoa Stream has the largest amount of habitat currently lost to diversions and the biota appears to be in the poorest condition. Restoration actions on Puohokamoa Stream would require modifications to three different diversions (ML-3 Manuel Luis Ditch, K-33 Koʻolau Ditch, S-9 Spreckels Ditch). The modifications to the diversions are relatively simple, with v-notches incorporated in the dam walls of all three diversions to allow flow downstream to provide suitable connectivity and instream habitat and to allow animal passage at the three diversion sites. DAR recommends the release of 5.4 cfs of water during the wet season to provide for minimum habitat flows and 0.3 cfs of water during the dry season to provide connectivity. These water releases would be apportioned among the different diversions. While Puohokamoa Stream would require more effort to restore than either East or West Wailua Iki Streams, a greater amount of native species habitat would be restored (2.8 km).

Waikamoi Stream

DAR Priority Rank: 4

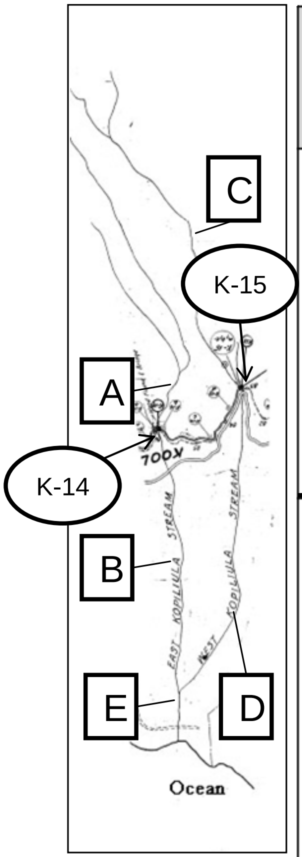


Area	Natural BFQ$_{50}$ (cfs)	Diverted BFQ$_{50}$ (cfs)	Wet Season H$_{min}$ (cfs)	Dry Season C$_{min}$ (cfs)	Habitat Units Restored (m)
No restoration requested for Diversion W-1 & NH-1 on Alo Tributary					
A	3.5	3.5	No change	No change	526
Diversion W-2 & S-10	 			Difficulty of diversion restoration: **Moderate (2)** Two diversion each simple (1)	
B	6.5	1.6	3.6 (+2.0)	1.7 (+0.1)	556
Diversion C-1				Difficulty of diversion restoration: **Simple (1)** Provide passage	
C	6.7	0.2	4.2 (+0.6)	1.3 (-0.4)	1,005
D	7.0	0.2			
Total Returned			2.6	-0.3	2,087

DAR Recommendations – Waikamoi has substantial habitat lost to flow diversions, yet the complexity of these diversion makes complete restoration more difficult. DAR recommends restoration actions be focused on the main channel of Waikamoi Stream and none on Alo tributary. DAR recommends the release of 2.6 cfs of water during the wet season to provide for minimum habitat flows and small amounts of water (0.1 to -0.3 cfs) during the dry season to provide connectivity. These water releases would be apportioned among the different diversions. Modifications in this restoration effort involve three of the five major diversion structures in the watershed (C-1 intake into Center Ditch, W-2 intake into Wailoa Ditch, S-10 Skimming Dam Intake into Spreckels Ditch). Modification of C-1, W-2 and S-10 intakes would involve a v-notch on each dam wall. Waikamoi Stream has additional diversions upstream of the Wailoa Ditch, but modifications of these diversions would provide less benefit to native species and are not proposed herein. The recommended restoration actions on Waikamoi Stream would result in the creation of over 2 km habitat for native species.

Kopili‘ula Stream

DAR Priority Rank: 5

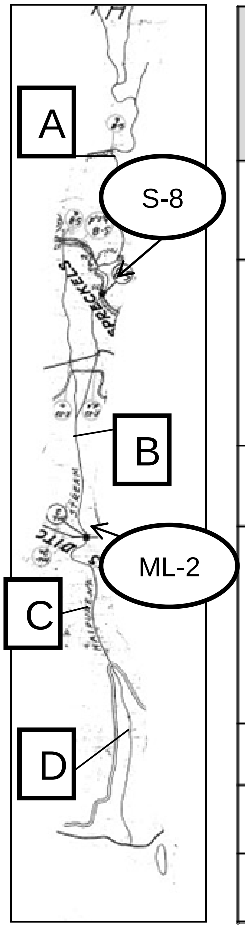


	Area	Natural BFQ$_{50}$ (cfs)	Diverted BFQ$_{50}$ (cfs)	Wet Season H$_{min}$ (cfs)	Dry Season C$_{min}$ (cfs)	Habitat Units Restored (m)
Puakaa Tributary (East Fork)	A	1.1	1.1	No change	No change	300
	Diversion K-14				Difficulty of diversion restoration: **Simple (1)** Provide passage	
	B	2.2	1.1	No change	+0.1	0
Kopiliula stream (West Fork)	C	5.0	5.0	No change	No change	901
	Diversion K-15				Difficulty of diversion restoration: **Moderate (2)** Deal with issue of comingling flows	
	D	6.5	1.2	4.2 (+3.0)	1.3 (+0.1)	805
	E	9.5	2.8	5.8 (+0)	2.9 (+0.0)	
Total Returned				3.0	0.2	2,007

DAR Recommendations - Kopili‘ula Stream is located near East and West Wailua Iki Streams and would provide more habitat than either of those streams, but the modifications to the diversions are more extensive. DAR recommends the release of 3.0 cfs of water during the wet season to provide for minimum habitat flows and 0.2 cfs of water during the dry season to provide connectivity. Flow release would be focused on the K-15 Diversion. Modifications to restore flow and allow passage would involve two diversion structures (K-15 Ko‘olau Ditch, K-14 Ko‘olau Ditch on Pua‘aka‘a tributary) to provide for suitable habitat downstream and animal passage at the diversion site. The modification of the K-15 diversion structure would involve a box flume from the upstream area of Kopili‘ula stream bypassing the area of co-mingling of the ditch and stream water and downstream of the diversion wall. The K-14 modification will likely involve a v-notch on the dam wall farthest away from the ditch entrance. These restoration actions would result in an additional 2 km of native speices habitat.

Haipua‘ena Stream

DAR Priority Rank: 6

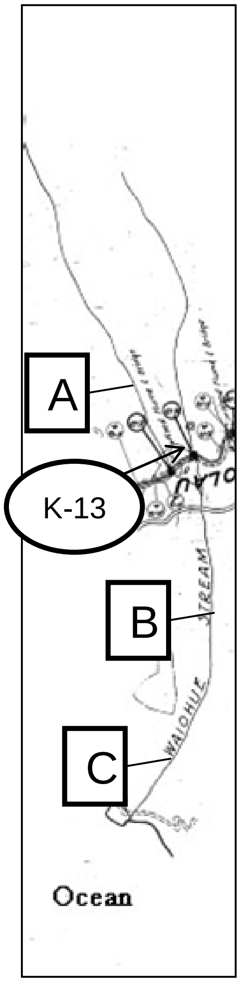


Area	Natural BFQ_{50} (cfs)	Diverted BFQ_{50} (cfs)	Wet Season H_{min} (cfs)	Dry Season C_{min} (cfs)	Habitat Units Restored (m)
A	3.6	3.6	No change	No change	0
Diversion S-8				Difficulty of diversion restoration: **Difficult (3)** No passage required	
B	4.3	0.8	2.8 (+2.0)	0.8 (+0)	548
Diversion ML-2				Difficulty of diversion restoration: **Difficult (3)** Need to bypass road	
C	4.9	0.5	3.3 (+0.5)	0.9 (+0.1)	951
D	5.5	1.1			
Total Returned			2.5	0.1	1,499

DAR Recommendations – Haipua‘ena Stream replaced Honomanū Stream based on the March 3, 2010 meeting with DAR, CWRM, Bishop Museum, and USGS agreement was reached regarding the recalibration of Honomanū Stream in the current HEP analysis, based on the consensus that the reach from the waterfall at the head of the canyon to the seaward terminus does not contain surface flow under base flow conditions. Haipua‘ena Stream has the potential to recover 1.5 km of lost native species habitat although the diversion modification are more difficult. Modifications would involve two diversion structures (ML-2 Manuel Luis Ditch, S-8 Spreckels Ditch) to provide for suitable habitat downstream and to increase upstream migration of native animals. DAR recommends the release of 2.5 cfs of water during the wet season to provide for minimum habitat flows and 0.1 cfs of water during the dry season to provide connectivity. These water releases would be apportioned among the different diversions. The modifications for ML-2 and S-8 diversions are complex in that the dam wall is supporting the road so the ability to achieve adequate fish passage will still require more analysis.

Waiohue Stream

DAR Priority Rank: 7

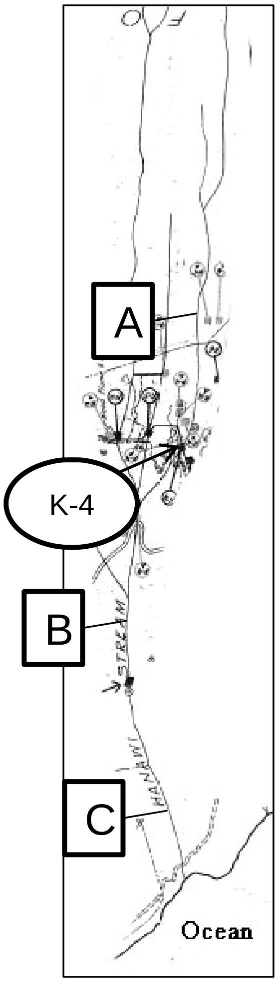


Area	Natural BFQ_{50} (cfs)	Diverted BFQ_{50} (cfs)	Wet Season H_{min} (cfs)	Dry Season C_{min} (cfs)	Habitat Units Restored (m)
A	5.0	5.0	No change	No change	562
Diversion K-13				Difficulty of diversion restoration: **Simple (1)** Provide passage at waterfall pool	
B	6.0	1.0	4.4 (+2.7)	1.3 (+0.1)	932
C	7.5	2.1			
Total Returned			2.7	0.1	1,494

DAR Recommendations – Waiohue is one of the better streams in the region biologically and would be enhanced by additional flow. DAR recommends the release of 2.7 cfs of water during the wet season to provide for minimum habitat flows and 0.1 cfs of water during the dry season to provide connectivity. Modification of K-13 intake into Ko'olau Ditch would involve digging of channel to lower elevation for overflow water to go down the right bank. This restoration action would provide an additional 1.5 km of suitable habitat for native stream animals.

Hanawī Stream

DAR Priority Rank: 8



Area	Natural BFQ_{50} (cfs)	Diverted BFQ_{50} (cfs)	Wet Season H_{min} (cfs)	Dry Season C_{min} (cfs)	Habitat Units Restored (m)
A	4.6	4.6	No change	No change	1,296
Diversion K-4				Difficulty of diversion restoration: **Simple (1)** Provide passage on right side of diversion	
B	24	19	No change	0.1	0
C	26	21			
Total Returned			0	0.1	1,296

DAR Recommendations - DAR recommends no additional flow restoration for this stream except that necessary to provide a wetted pathway past the diversion structure (approximately 0.1 cfs). This restoration action would provide an additional 1.3 km of suitable habitat for native stream animals. The only modification would be to the K-4 intake into Koʻolau Ditch to provide for animal passage and reduce entrainment of newly hatched larvae at the diversion site. This would involve at v-notch on the dam wall right bank. The lower section of Hanawī Stream is highly productive habitat for native stream animals and has large springs which provide flow and habitat even during drought periods. Overall, Hanawī Stream is an outstanding stream with a healthy and diverse population of native species, and therefore reconnecting the upper and lower sections would protect and enhance the ecological integrity of this particularly valuable stream.

Table 1. Recommended East Maui Stream Flow Ranks

							Rankings						Watershed Atlas Rating		
Stream	**Habitat Units** (HU in m)	**# of Diversions**	**C_{min} - dry season** (= 20% tbf)	**H_{min} - wet season - cfs at H90** (= 64% tbf)	**Terminal Falls**	**HU**	**Poorest Condition - Species**	**POD - Effort to fix**	**Efficient Water Use**	**Average**	**FINAL RANK**	**Geography**	**TWR**	**TBR**	**COR**
E. Wailua Iki	2,402	1	0.2	3.2	No	2	2	1	3	2	1	e	7	7	8
W. Wailua Iki	2,218	1	0.4	3.5	No	3	4	1	5	3.25	2	e	7	7	8
Puohokamoa	2,801	3	0.3	5.4	No	1	1	3	8	3.25	3	w	8	5	7
Waikamoi	2,087	5	0	2.6	Yes	4	6	3	2	3.75	4	w	7	7	8
Kopiliʻula	2,007	2	0.2	3	No	5	5	3	4	4.25	5	e	8	7	8
Haipuaʻena	1,499	3	0.1	2.5	Yes	6	3	6	5	5	6	w	8	5	6
Waiohue	1,494	1	0.1	2.7	No	7	7	1	7	5.5	7	e	7	8	8
Hanawī (1)	1,296	1	0.1	0	No	8	8	1	1	4.5	8	e	8	8	9
Total	15,804	17	1.4	22.9											

Hanawī (1) no flow amounts are provided as no change in current flow condition are recommended.

Habitat Units reflect the total amount of habitat for the native species of concern currently lost to flow diversion or barriers based on H90
# of diversion is based on the surveys by DAR and CWRM
C_{min} - dry season are the minimum flow to provide connectivity
H_{min} - wet season-H90 are the percent of habitat based on the USGS IFIM study for East Maui Streams
Terminal Falls are waterfalls at the mouth of a stream that restrict upstream movement of non-climbing species
In the ranking sections:
Habitat Units are the ranked order from column 1
Poorest Condition - Species ranks stream that are in the worst condition first and lack some native species
POD - Effort to fix the Point of Diversion (POD) and an estimate of the difficulty of providing fish passage. Diversion was scored 1 to 3 for increasing difficulty and resulting sum of all diversion scores were ranked lowest to highest.
Efficient Water Use was the ranking of HU/cfs at H90. More habitat per cfs scored better. Hanawi does not require water return thus we ranked it 8 (n/a).
Average was the average of the first four ranking columns.
FINAL RANK was the ranking of the average with West Wailua Iki ranked ahead of Kopiliula due to its easier diversion fix.
Geography show in which section of the area the streams were located in. We wanted to spread out the stream restoration if possible.
Watershed Atlas ratings are shown in the last three columns
TWR = Total watershed rating
TBR = Total biological rating
COR = Combined overall rating

Table 2. Habitat Units for the three categories of Native Species-‘o‘opu, hihiwai, and ‘opae

	Habitat Units (HU in m)										
	‘o‘opu						**hihiwai**	**‘opae**			total of all spp
Stream	‘o‘opu akupa	‘o‘opu naniha	‘o‘opu nakea	‘o‘opu nopili	‘o‘opu hi‘ukole	total ‘o‘opu		‘opae ‘oeha‘a	‘opae kala‘ole	total ‘opae	
Waikamoi	0	0	208	142	1,049	1,399	325	363	0	363	2,087
Puohokamoa	12	3	405	288	1,178	1,886	426	443	45	488	2,801
Haipua‘ena	23	7	252	154	721	1,157	191	122	28	151	1,499
W. Wailua Iki	10	3	213	181	913	1,322	182	685	29	714	2,218
E. Wailua Iki	12	4	272	308	959	1,555	298	510	39	549	2,402
Kopili‘ula	5	1	152	152	863	1,174	165	651	16	668	2,007
Waiohue	7	1	192	173	651	1,024	206	241	23	265	1,494
Hanawī	0	0	25	14	587	626	17	652	0	652	1,296
Total	70	20	1,721	1,413	6,920	10,144	1,811	3,668	181	3,849	15,804

Habitat Units reflect the total amount of habitat for the three categories of native species: ‘o‘opu, hihiwai, and ‘opae and they are all based on H100 for the entire watershed therefore, the total of all species is larger that the total habitat units for the streams in Table 1. which reflects habitat units below and between the diversions.

Table 3. Points of Diversions on each stream and effort of modification for fish passage and entrainment

	Points of Diversion-effort of modification					
Stream	Diversion 1	Diversion 2	Diversion 3	Diversion 4	Diversion 5	Total
Puohokamoa (3)	(ML-3)=1	(K-33)=3	(S-9)=3			7
Waikamoi (5)	(C-1)=1	(S-10)=1	(W-2)=2	(NH-1)=3	(W-1)=3	8
Haipua‘ena (3)	(ML-2)=3	(S-8)=3				6
Kopili‘ula (2)	(K-15)=2	(K-14)=1				3
E. Wailua Iki (1)	(K-16)=1					1
W. Wailua Iki (1)	(K-17)=1					1
Waiohue (1)	(K-13)=1					1
Hanawī (1)	(K-4)=1					1

Streams listed with number and designation (EMI) of diversions considered for modification
Points of Diversion-effort of modification reflect the difficulty in modifying the diversions to allow fish passage on each stream starting at the lowest diversion
Diversions were scored 1 to 3 for increasing difficulty with resulting sum of all diversion scores

Appendix D

Letter of May 17, 2010

State of Hawaii
Department of Land and Natural Resources
DIVISION OF AQUATIC RESOURCES

May 17, 2010

TO: Ken C. Kawahara, Deputy Director-Water
Commission on Water Resources Management

CC: Laura H. Thielen, Chairperson
Department of Land & Natural Resources

FROM: Robert T. Nishimoto, Environmental Program Manager
Division of Aquatic Resources

SUBJECT: Request for stream flow estimates for H_{50} and H_{70} and the Division of Aquatic Resources' position statement on Minimum Habitat Flows

The Division of Aquatic Resources (DAR) is responsible for the protection and management of living aquatic resources in the waters of Hawaii. The DAR realizes that the Commission on Water Resource Management (CWRM) has the responsibility of balancing the current and future value of multiple uses of water when rendering its decisions on specific Instream Flow Standards. By contrast, the DAR's recommendations focus only on the requirements of the native aquatic biota that fall within the scope of our authority, and do not consider additional instream or offstream uses of stream water. This memorandum reflects DAR's position on the recommendations that support restoration of native species habitat, migratory pathways for upstream recruiting individuals and downstream drifting larvae, and overall population structure and health for eight native fish and macroinvertebrate species inhabiting East Maui streams.

On March 11, 2010, the Division of Aquatic Resources met with Native Hawaiian Legal Corporation (NHLC), Commission on Water Resource Management (CWRM), Hawaiian Commercial & Sugar (HC&S), and Maui Department of Water Supply to discuss current data that CWRM has received to date. The DAR presented a spreadsheet of East Maui Stream flow ranks for H_{90} and H_{100} which are the percent of habitat based on the USGS IFIM study for East Maui Streams. It was requested that DAR recalculate the flow ranks for H_{50} and H_{70}. H_{50} and H_{70} were not presented by DAR as DAR staff had already determined that these flow rates for these habitat levels would not support all aspects of the native species life history requirements.

The former administrator to DAR misconstrued DAR's position to the March 11th meeting participants when he stated that DAR could calculate H_{50} and H_{70} flow rates. While DAR has the ability to calculate flows for any habitat level based on the USGS

IFIM study, DAR does not believe that H_{50} or H_{70} reflect viable flow rates for the protection of native aquatic biota.

On May 4, 2010, the DAR was directed by the DLNR administration to provide the H_{70} and H_{50} flow estimates for the DAR recommended streams and these are provide in this document. It is understandable why such a request would be made. Almost by definition, there is an expectation that a linear relationship exists between the amount of habitat and the number of animals. Thus it is tempting to assume that H_{70} is only 20% less habitat then H_{90} and therefore would result in only 20% less animals. Similarly, H_{50} is only 20% less then H_{70} and therefore only an additional 20% less animals. This conclusion IS NOT supported by the DAR.

DAR fully comprehends the rationale, methods, and results of the USGS IFIM study, and thus understands that it considers only a limited portion of the life history requirements of the native species. The USGS IFIM study primarily considered the attributes of water depth, velocity, and substrate, yet did not consider important components like food production or availability, the presence of suitable refuges, pathways for migration, the availability of spawning habitats, flow mediated triggers for reproductive events, or seasonally variable flow rates. The is not intended as a criticism to the quality of the work provided by USGS, only that as USGS states in their report, “These results are intended to be used along with other biological and hydrological information in development, negotiations, or mediated settlements for instream flow requirements.” DAR’s position is that H_{min} (H_{90}) or 64% of the naturally occurring base flow represents the minimum viable flow expected to provide suitable conditions for growth, reproduction, and recruitment of native stream animals. Flows lower than the minimum habitat flow would serve primarily maintenance flows where the adult animals “survive” until more suitable flows return.

The DAR’s recommendations are based on several lines of evidence. First, DAR biologists and technicians spent considerable time and effort surveying habitat and animal populations in these streams. The results of these surveys found that while some areas within the streams do contain native animals, many stream sections had few or no native species. Second, the DAR compared the results of the stream surveys with estimates of expected native species occurrence by utilizing the Hawaiian Stream Habitat Evaluation Procedure (HSHEP) analytic model, with the results for the 19 East Maui streams provided to CWRM staff on November 20, 2009. The results of the HSHEP also suggest that native animals are missing from a number of stream sections where they should naturally exist. Finally, the DAR used available information and the extensive experience of its staff to develop a general life history description of island stream animals and used this in determining the final list of actions needed to support restoration of native species in these 19 streams.

A general consensus among DAR staff and many outside researchers regarding stream flow and native stream animals’ life history is that the animals’ behavior changes with changes in seasonal stream flow. For adult animals, periods of higher base flow triggers many reproductive events. The animals react to the higher flows to initiate courtship and spawning. The animals attached the fertilized eggs to the substrate (fish and mollusks) or to their body (crustaceans). After a period of development, the larvae hatch from the eggs and drift downstream. The newly hatched larvae have a short period of time to reach the ocean before dying thus higher flows serve to successfully transport larger numbers of newly hatched larvae from spawning sites further inland. Once the larvae reach the ocean, they spend 3 to 5 months (in most species) developing in ocean waters. When the animals are ready to return to the stream, they usually return in mass in response to high stream flow events. The small animals, averaging ¼ to 1 inch long, move upstream to find suitable adult habitat. The juveniles that find suitable habitat mature into adults. Adults live for multiple years and can spawn multiple times in a single spawning season. There is evidence in Hawaii and in other Pacific islands that native island stream animals' reproduction commences with the beginning of the wet season and recruitment of young animals peaks toward the end of the wet season. As a result of this generalized life history pattern, the creation of an artificial "wet season" with higher base flows in a flow controlled stream may support many of the animals life history requirements.

DAR supports the following positions regarding restoration efforts in East Maui Streams.

As a general position regarding stream diversion and native aquatic animals:

- The removal of stream diversions and the complete restoration of stream flow would be the best possible condition for native aquatic animals. DAR understands that management of the resource is a balance between the needs of the animals and the needs of people thus supports some use of water from East Maui Streams.
- In no case are additional diversions of stream water recommended, although current levels of stream flow diversion may be appropriate on some streams. Flow restoration is only recommended on 8 of the 19 streams under consideration.
- The prioritization of the East Maui Streams is based upon the "biggest bang for the buck" concept, where priority is placed on streams with the greatest potential to increase suitable habitat for native species.
- The restoration of suitable flows to a single stream is more appropriate than the return of inadequate flow to multiples streams. DAR supports the trade-offs on the restoration of a smaller number of streams with sufficient water (see below) over the return of insufficient water (for example at H_{50} or H_{70} levels) to a larger number of streams.
- Restoration of stream flow should reflect the water budget of the individual stream catchment. The use of trans-basin water diversions from ditches to restore stream sections should be avoided where at all possible.
- Co-mingling of stream and ditch flows should be avoided where at all possible to limit the potential spread of invasive aquatic species.
- Restoration of streams should be spread out in a geographic sense. This will provide a greater protection against localized habitat disruptions, a wider benefit to estuarine and nursery habitat for nearshore marine species, and result in more comprehensive ecosystem function across the entire East Maui sector.
- Implementation of a long-term monitoring program to analyze the effect of restored flows to native biota, their health, and all aspects of their life history.

With respect to amount of water flow needed in the stream:

- The goal of returning H_{min} during the wet season and C_{min} during the dry season is considered the minimum viable flow to achieve suitable conditions for native aquatic animals.
- Minimum viable habitat flow (H_{min}) for the maintenance of suitable instream habitat is defined as 64% of Median Base Flow (BFQ_{50})(also defined as H_{90} by USGS studies). DAR expects that these flows will provide suitable conditions for growth, reproduction, and recruitment of native stream animals.
- Minimum viable connectivity flow (C_{min}) for the maintenance of a wetted pathway between the ocean and stream habitats is defined as 20% BFQ_{50}. These flows are expected to allow adult animals to move among habitats and allow recruiting animals to move upstream to suitable habitats. These flows are considered by DAR to be too low to expect suitable long-term growth and reproduction of native stream animals.
- Seasonally adjusted flows, H_{min} during the wet season and C_{min} during the dry season may mimic the natural flow variability observed in Hawaiian streams and support most ecological functions required by the stream animals. Seasonally adjusted flows would also provide maximum water for human use during periods of highest needs in the dry season and provide increased water to the stream animals during the period of lowest demand during the wet season. The increased wet season flows are intended to trigger reproductive events and maximize production of native animals.
- A “share-the-pain” approach in dealing with droughts may be appropriate. When an area is experiencing drought conditions then instream flow requirements may be suspended. The native aquatic animals in Hawaii streams have evolved in a system where droughts and the resultant low flows periodically occur and the animals can repopulate a stream when more favorable conditions return. This is not supportive of the continuous man-made artificial drought conditions currently experienced in many East Maui Streams as a result of stream diversion.

With respect to entrainment of native animals in stream diversions:

- The DAR realizes that complete elimination of entrainment for native stream animals is unlikely, but an avoidance of entrainment at diversion locations is important to maximize populations of native stream animals while minimizing the negative impacts from stream diversions.
- As newly recruiting animals move upstream to adult habitats, they follow the available path of water in the stream. Thus release of water from sluice gates in the immediate vicinity of diversion intakes serves to funnel animals to the intake and results in high rates of entrainment (and ultimately death) of animals migrating upstream. Therefore, water releases should provide a pathway as far away as possible from the point of diversion to minimize entrainment of upstream migrating animals.
- As newly hatched animals travel downstream to the ocean, they passively drift with the stream water. Thus release of water from sluice gates in the immediate vicinity of diversion intakes serves to concentrate animals near the intake and

results in high rates of entrainment (and ultimately death) of animals drifting downstream. Therefore, water releases should provide a pathway as far away as possible from the point of diversion to minimize entrainment of downstream drifting animals.

The following are the flow recommendations for the 8 East Maui Streams (Table 1). The H_{min} and C_{min} flow are provided (highlighted in green) along with the USGS H_{70} (removal of 63% of median base flow for all species less opae and 77% of median base flow for opae) and USGS H_{50} (removal of 83% of median base flow for all species less opae and >99% of median base flow for opae). The DAR recommendations of H_{min} and C_{min} flows represent essential actions that will greatly enhance native species habitat, connectivity, and overall population structure and viability. In no case are additional diversions of stream water recommended.

Note: DAR has seen little evidence in its surveys across the State of Hawaii that substantial (83%) to nearly complete (>99%) removal of base flow from a stream results in only losing 50% of its animals as suggested by the USGS study and thus does not support the designation of these flow amounts as 70 and 50% of available habitat.

Table 1. Various level of flow diversion for East Maui streams.

	Average stream flow below lower most diversion	H_{min}: DAR Recommended minimum habitat flow for wet season (H_{90} from USGS)	USGS H_{70} for all animals less opae (not supported by DAR)	USGS H_{70} for opae (not supported by DAR)	C_{min}: DAR Recommended minimum connectivity flow for dry season	USGS H_{50} for all animals less opae (not supported by DAR)	USGS H_{50} for opae (not supported by DAR)
		Amount of flow (cfs) remaining after diversion of x% of Median Base flow (BFQ_{50})					
Stream	Undiverted BFQ_{50} (cfs)	H_{min}: 36%	H_{70}: 63%	H_{70}: 77%	C_{min}: 80%	H_{50}: 83%	H_{50}: 99%
Waikamoi	6.9	4.4	2.5	1.6	1.4	1.2	0.1
Puohokamoa	10.5	6.7	3.9	2.4	2.1	1.8	0.1
Haipuaena	5.2	3.3	1.9	1.2	1.0	0.9	0.1
W. Wailua Iki	7.0	4.5	2.6	1.6	1.4	1.2	0.1
E. Wailua Iki	7.0	4.5	2.6	1.6	1.4	1.2	0.1
Kopiliula	8.0	5.1	3.0	1.8	1.6	1.4	0.1
Waiohue	6.8	4.3	2.5	1.6	1.4	1.1	0.1
Hanawï	no flow restoration recommended only modification of diversion for passage						

We apologize for any confusion created by the lack of clarity surrounding DAR's position on suitable instream flow requirements to support native aquatic animals. We hope this memorandum clarifies DAR's position on the subject. We understand the developing appropriate instream flow standards is a complex and difficult task and hope we can continue to support CWRM by providing well-reasoned scientific information that supports DAR's mandate to protect and manage the living aquatic resources in the waters of the State of Hawaii.

Appendix E

Monitoring Changes in Habitat, Biota, and Connectivity Resulting From Water Returns in the East Maui Streams of East Wailua Iki, West Wailua Iki, and Waiohue

Glenn R. Higashi[1]

James E. Parham, Ph.D.[2]

Skippy Hau[1]

Eko K. Lapp[1]

Darrell G.K. Kuamoo[1]

[1]Division of Aquatic Resources

[2]Bishop Museum

Jan. 6, 2015

Table of Contents

List of Figures

List of Tables

Executive Summary:

The Department of Land and Natural Resources (DLNR) is the lead agency within the State of Hawaii tasked with managing natural resources and the plants and animals that depend on them. Understanding and managing for the continuation of healthy instream habitats and suitable migratory pathways for native amphidromous stream animals is the responsibility of the Hawaii Division of Aquatic Resources (DAR), a division within the broader DLNR. Also within DLNR, is the Commission on Water Resource Management (CWRM). This department is responsible for balancing all beneficial (current and future) uses of water when rendering decisions on specific allocations for competing uses. In May 2001, the CWRM received petitions from the Native Hawaiian Legal Corporation (NHLC) seeking to amend the Interim Instream Flow Standard (IIFS) to restore stream flow for 27 East Maui streams. The contested case concluded in 2010, when the IIFS was set by CWRM for the 27 streams.

To assess the impact of the IIFS for East Maui streams and to support the adaptive management approach, DAR undertook a multi-year monitoring effort on several of the affected streams. Specifically, the goal of this study was to assess the impacts of the IIFS flow restoration on native species by:

1. Determining changes to the quantity of available habitat
2. Determining changes to the population structure
3. Assessing the changes in connectivity between the lower and upper stream areas

To detect if flow changes mandated in the IIFS resulted in positive changes in a stream over time, monitoring stations were established in three East Maui Streams that had water restored by the IIFS. The streams were East Wailua Iki, West Wailua Iki and Waiohue. The habitat and biota surveys were conducted at each monitoring station on a quarterly basis. Surveys began prior to the water restoration and continued for two years after flow restoration commenced.

The study results were not definitive, but do suggest some general conclusions. Some changes to instream habitat at the upper survey stations were observed in response to the higher wintertime flow releases. In general, dry, disconnected or slow-water habitats were replaced by more connected swift-water habitats. These improvements to instream habitat reflected a change to a more stream-like environment. Based on our knowledge of stream animals found in mid to upper stream reaches, these changes should result in more suitable instream habitat. In contrast to the improvements observed at upper stations during the wintertime flow releases, the lower summer flows showed little to no habitat improvement.

In the upper stations of all streams, stream animal assemblages did not show the healthy characteristics. In general, we did not see consistent patterns of occurrence, growth in numbers, or increases in size classes of the animals. As expected based on its habitat and range distribution, *Atyoida bisulcata* was the most common species and some recruitment and growth were observed in East and West Wailua Iki streams. While conditions may have been suitable for

A. bisulcata, few *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Neritina granosa* were observed in the upper stations suggesting poor quality habitat for these species over time.

At the lower monitoring stations, little change was observed to instream habitat with respect to either winter or summer flow releases. This was not an unexpected result. The lower stations were just upstream from the stream mouth and had perennial flow prior to the flow restorations. In the lower stations of all streams, the stream animal assemblages appear healthy and diverse with good recruitment from the ocean and display composition structure typical of Hawaiian streams. A range of size classes for most stream animals were observed and this pattern likely reflects that suitable conditions existed for feeding, growth, courtship and reproduction.

In our assessment of connectivity, we only observed consistent recruitment of small individuals for *Atyoida bisulcata* to the upper stations over time suggesting that adequate connectivity flows were present. While the upper sites showed some connectivity for *A. bisulcata*, we did not observe increases in recruitment numbers comparing post-release periods to pre-release periods for *Lentipes concolor*, *Sicyopterus stimpsoni*, or *Neritina granosa.* This result suggests that flows for connectivity may have been insufficient for these species.

The correlation between return flows, habitat, and biota was weak. This may be due to a number of factors including: changing environmental conditions (e.g. rainfall, drought, flash flooding), short monitoring period (<4 years), and/or that summer flows were detrimental to gains in habitat and biota from the winter flows. A longer monitoring period with more stations distributed more thoroughly throughout the stream may improve results, but this was not possible due to time and funding constraints.

It is important to remember that the upper stations were below the diversions and therefore passage and entrainment issues at the diversions were not addressed in this study. Passage and entrainment at water diversion sites is an important topic and will need to be addressed for more effective stream animal restoration to occur.

The results of this study are important for several reasons. First, this represents the first multi-stream attempt at monitoring changes over time to stream biota and habitat with respect to stream flow restoration. Second, the results of this work are intended to be used in an iterative process for setting an Interim Instream Flow Standard within an adaptive management framework. Finally, this study was a direct observation of the suitability of seasonal flows for use in IIFS for Hawaiian streams.

Overall, the seasonal flow hypothesis (higher winter flows and lower summer flows) was conceptually coherent, yet not supported by the data. The lack of support for the seasonal flow hypothesis may reflect that the prescribed flow amounts were insufficient (i.e. needed higher flows in summer) or that a year round minimum flow is more appropriate in East Maui streams.

Introduction:

The Department of Land and Natural Resources (DLNR) is the lead agency in the State of Hawaii tasked with managing natural resources and the plants and animals that depend on them. In the case of Hawaiian streams, the waters that accumulate from rainfall on headwater slopes and flow downstream to the ocean provide essential habitat for Hawaii's unique freshwater flora and fauna. While the stream habitats are critical to native fish and macro-invertebrates, an open and direct link to the sea is also vital to their existence. Understanding and managing for the continuation of healthy instream habitats and suitable migratory pathways for native amphidromous stream animals is the responsibility of the Hawaii Division of Aquatic Resources (DAR), a division within the broader DLNR. Also within DLNR is the Commission on Water Resource Management (CWRM) which has the responsibility of balancing all beneficial (current and future) uses of water when rendering decisions on specific allocations for competing uses. The amount of water left in the stream to protect public trust values which includes the maintenance of fish and wildlife habitat is described within an Instream Flow Standard.

In May 2001, the CWRM received petitions from the Native Hawaiian Legal Corporation (NHLC) seeking to amend the Interim Instream Flow Standard (IIFS) to restore stream flow for 27 East Maui streams. Substantial information was gathered on stream flow (Gingrich 2005), habitat availability (Gingrich and Wolff 2005, Parham et al. 2009), watershed conditions (Parham et al. 2008), and animal populations (Higashi et al. 2009 a, b, c) to better understand the implications of instream flow and habitat restoration. The contested case concluded in 2010, where the IIFS was set by CWRM for the 27 streams. To better understand the impact of the 2010 IIFS on stream animal habitat and populations, DAR monitored three of the streams to determine whether the water returns improved conditions as hypothesized during the flow standard deliberations. In summer of 2014, a decision was made to revisit the IIFS for all 27 east Maui streams. This report documents the results of the monitoring effort and was compiled to support of the reanalysis of the flow standards.

In the 2010 IIFS deliberations, DAR proposed seasonal flow regimes with respect to native biota needs based on the hypothesis that the animals' behavior may change with seasonal changes in base flow. There is evidence in Hawaii and in other Pacific islands that native island stream animals' reproduction commences with the beginning of the wet season and recruitment of young animals peaks toward the end of the wet season (Fitzsimons et al. 2002). The general management concept applied to the flow-controlled East Maui streams focused on the creation of an artificial "wet season" with higher base flows to support most of the animals' life history requirements, while the presence of lower flows during a "dry season" could maintain habitat connectivity until more suitable flows returned with the next "wet season". The wet and dry season flows were also hoped to be more complementary of human water use patterns. When rains are most common during Hawaiian winters, the need for irrigation water may be lessened and as a result more water should be available for instream habitat. Conversely, during the drier

Hawaiian summer season, human demand for water is greater and as a result, less was requested to support the animals’ needs.

In the deliberations, DAR termed this approach “share the pain”. The “share the pain” moniker reflected the notion that during the drier summer periods neither man’s nor stream animals’ needs would be fully supported. Each would experience some “pain” from the IIFS. For man’s off-stream uses, 100% diversion of stream flow would not be accepted. A dry stream is unsuitable habitat for aquatic organisms. There must be some water in the stream for animals to survive. For the animals, minimal flow rates would allow the animals to subsist, but likely would not support much reproduction. During wetter periods, the IIFS was set to fully support the stream animals’ courtship, spawning, and migratory needs so that a new generation of animals could be born, drift down to the ocean and then migrate back up the streams prior to the onset of lower dry season flows. For man, returning more water to streams during periods of greater water availability was hoped to be less onerous on water user’s needs.

It is also important to acknowledge that setting an IIFS to “fully” or “partially” support native Hawaiian stream animals needs is not an exact science. We based our recommendations on many thousands of observations of these animals from streams all across the State and from the best professional judgments derived from years of studying Hawaiians streams and the animals in them. With that said, recommending a single flow value that is neither too large nor too small to support the many needs of animals that live in torrential Hawaiian streams is difficult. This difficulty is not unique to managing Hawaiian streams; the presence of uncertainty in natural resource management is the norm. As a result, the practice of adaptive management is widespread in situations of uncertainty (Stankey et al. 2005). With adaptive management, studies focus on whether or not the current standards are achieving the goals with the express intent to “adapt” to the new information as it becomes available.

To assess the impact of the IIFS for East Maui streams and to support the adaptive management approach, DAR undertook a multi-year monitoring effort on several of the affected streams. Specifically, the goal of this study was to assess the impacts of the IIFS flow restoration on native species by:

4. Determining changes to the quantity of available habitat
5. Determining changes to the population structure
6. Assessing the changes in connectivity between the lower and upper stream areas

Methods:

To detect if flow changes mandated in the IIFS resulted in positive changes in a stream over time, monitoring stations were established in three East Maui Streams that had water restored by the IIFS. The streams were East Wailua Iki, West Wailua Iki and Waiohue. These three streams had stream flow and habitat data collected by USGS (Gingrich 2005, Gingrich and Wolff 2005) and biota surveys by DAR (Higashi et al 2009 a, b, c) thus providing good background on the streams. Each stream had two monitoring stations. One monitoring station was located in the lower reach and one in the upper reach for a combined total of six monitoring stations (Figures 1 and 2). For all three streams, the upper reach monitoring station was above the Hana Highway and below the diversions. Monitoring stations in the middle reaches were not established due to inaccessibility from either Hana Highway or by helicopter.

East and West Wailua Iki streams are in close proximity to each other and are connected by a common embayment (Figure 3). The East Wailua Iki stream mouth is commonly closed to the ocean by a cobble berm, while West Wailua Iki stream mouth is nearly always open to the ocean. Waiohue Stream is small, narrow, and steep with a small embayment to the east of the Wailua Iki Streams (Figure 4). Like West Wailua Iki, Waiohue stream mouth is rarely closed to the ocean by a berm.

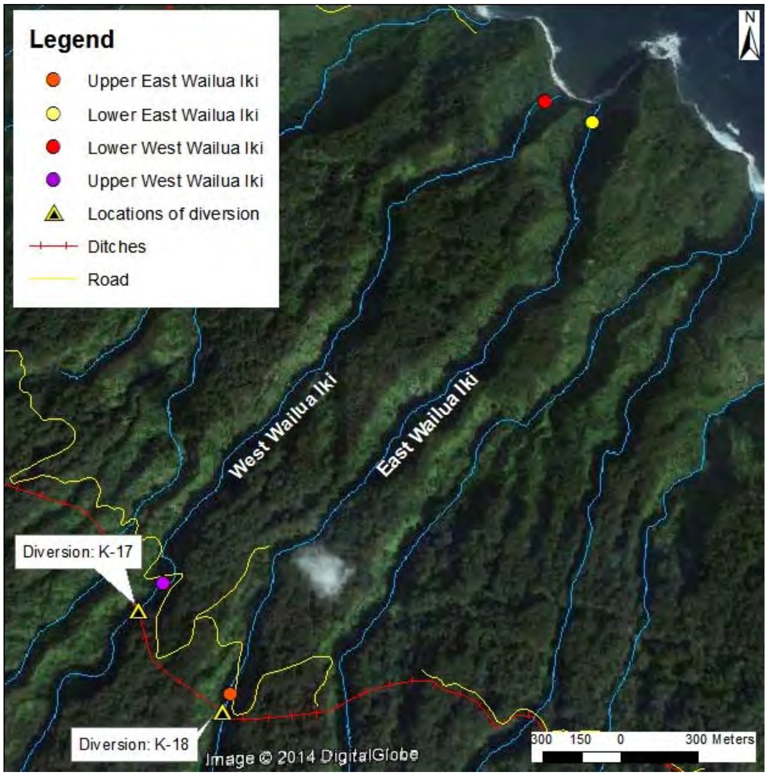


Figure 1. Locations of monitoring stations in the lower and upper reaches of West and East Wailua Iki Stream.

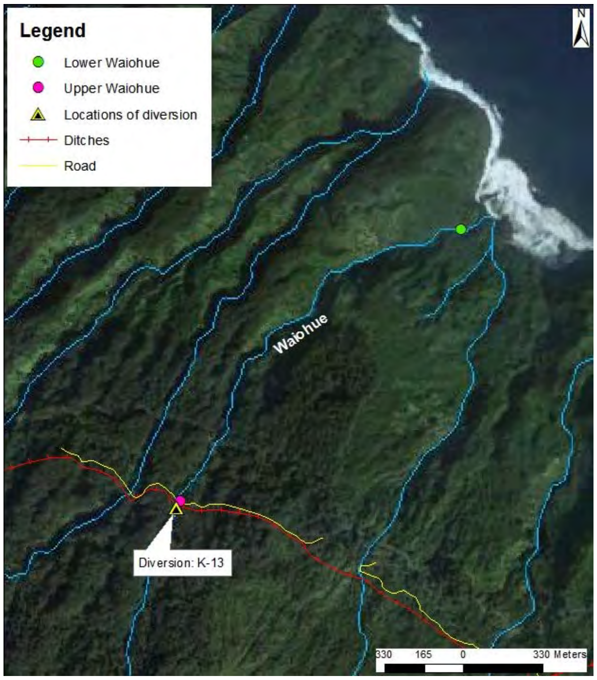


Figure 2. Locations of monitoring stations in the lower and upper reach of Waiohue Stream.

Figure 3. Aerial view of East (left) and West (right) Wailua Iki stream mouths

Figure 4. Aerial view of Waiohue stream mouth.

Survey Methods:

The habitat and biota surveys were conducted at each monitoring station on a quarterly basis (Table 1). Surveys began prior to the water restoration and continued for two years after flow restoration commenced. During the period prior to flow restoration, baseline data were collected to assess the current native biota distribution and was used to compare with data obtained from these monitoring sites after the water releases. The data collected from the same surveys locations were intended to identify trends involving stream fauna, instream habitat, and the success of fish passage (connectivity). No monitoring surveys were conducted during April 2011 due to inclement weather conditions as well as procurement difficulties in obtaining helicopter services.

A monitoring station was 100 meters long and was internally divided down the stream center into left and right portions and into four 25-meter sites. Reference locations at each monitoring stations were marked by stainless steel lag bolts to allow return to the same locations over time. Prior to the survey, the individual sites within the overall station were flagged at their lower, middle and upper boundaries using colored surveyors tape. This resulted in four cells per site (two left and two right side cells). Additionally, the dividing lines between cells were designated as transects resulting in a total of 8 transects per sampling station. Figure 5 shows a hypothetical sampling station with the internal breakdown of measurement units.

Table 1. Monitoring Dates for East Maui Streams Flow Restoration

Year	Date	Stream	Station	Data Sites	Personnel***
2010	19-Oct	West Wailua Iki	Lower	1,2,3,4	LN, NH, SH
		East Wailua Iki	Lower	1,2,3,4	DK, TS
	30-Nov	Waiohue	Upper	1,2,3,4	DK, SH
	1-Dec	Waiohue	Lower	Rained out	DK, SH
	2-Dec	West Wailua Iki	Upper	1,2,3,4	DK, SH
		East Wailua Iki	Upper	1,2,3,4	DK, SH
2011	12-Jul	West Wailua Iki	Upper	1,2,3,4	NH, SH
		East Wailua Iki	Upper	1,2,3,4	DK, VG
	13-Jul	West Wailua Iki	Lower	1,2,3,4	NH, SH
		East Wailua Iki	Lower	1,2,3,4	DK, VG
	14-Jul	Waiohue	Upper	1,2,3,4	NH, SH
		Waiohue	Lower*	1,2,3	DK, VG
	11-Oct	West Wailua Iki	Upper	1,2,3,4	NH, SH
		East Wailua Iki	Upper	1,2,3,4	DK, GH
	12-Oct	West Wailua Iki	Lower	1,2,3,4	NH, SH
		East Wailua Iki	Lower	1,2,3,4	DK, GH
	13-Oct	Waiohue	Upper	1,2,3,4	DK, GH
		Waiohue	Lower*	1,2,3	NH, SH
2012	24-Jan	West Wailua Iki	Upper	1,2,3,4	GH, SH, VG
		East Wailua Iki	Upper	1,2,3,4	DK, NH, RY
	25-Jan	West Wailua Iki	Lower	1,2,3,4	GH, SH, VG
		East Wailua Iki	Lower	1,2,3,4	DK, NH, RY
	26-Jan	Waiohue	Upper	1,2,3,4	DK, NH, RY
		Waiohue	Lower*	1,2,3	GH, SH, VG
	11-Apr	West Wailua Iki	Lower	1,2,3,4	SH, VG
		East Wailua Iki	Lower	1,2,3,4	DK, GH
	12-Apr	Waiohue	Upper	1,2,3,4	DK, GH
		Waiohue	Lower*	1,2,3	SH, VG
		West Wailua Iki	Upper	1,2,3,4	DK, GH
	13-Apr	East Wailua Iki	Upper	1,2,3,4	DK, GH, SH
	10-Jul	West Wailua Iki**	Upper	Rained Out	SH, VG
		East Wailua Iki	Upper	1,2,3,4	DK, EL, GH
	11-Jul	West Wailua Iki	Lower	1,2,3,4	SH, VG
		East Wailua Iki	Lower	1,2,3,4	DK, EL, GH
	12-Jul	Waiohue	Upper	1,2,3,4	DK, EL, GH
		Waiohue*	Lower	1,2,3	SH, VG
	7-Aug	West Wailua Iki	Upper	1,2,3,4	SH
	10-Oct	West Wailua Iki	Upper	1,2,3,4	NH, SH
		East Wailua Iki	Upper	1,2,3,4	DK, GH
	11-Oct	West Wailua Iki	Lower	1,2,3,4	NH, SH
		East Wailua Iki	Lower	1,2,3,4	DK, GH
	12-Oct	Waiohue	Upper	1,2,3,4	DK, GH
	12-Oct	Waiohue*	Lower	1,2,3	NH, SH
2013	29-Jan	West Wailua Iki	Upper	1,2,3,4	SH, VG
		East Wailua Iki	Upper	1,2,3,4	DK, GH
	30-Jan	West Wailua Iki	Lower	1,2,3,4	SH, VG
		East Wailua Iki	Lower	1,2,3,4	DK, GH
	31-Jan	Waiohue	Upper	1,2,3,4	DK, GH
		Waiohue*	Lower	Rained Out	SH, VG
	23-Apr	West Wailua Iki	Upper	1,2,3,4	NH, SH
		East Wailua Iki	Upper	1,2,3,4	DK, GH
	24-Apr	West Wailua Iki	Lower	1,2,3,4	NH, SH
		East Wailua Iki	Lower	1,2,3,4	DK, GH
	25-Apr	Waiohue	Upper	1,2,3,4	DK, GH
		Waiohue*	Lower	1,2,3	NH, SH

Waiohue*- Lower Station only has 1, 2, 3 sites due to small waterfall in the lower site
West Wailua Iki** - Upper Station “Rained Out” but made up on 7-Aug

Personnel*** (all with DAR):
DK – Darrell Kuamoo; EL – Eko Lapp; GH – Glenn Higashi; LN – Lance Nishiura; NH – Neal Hazama; RY – Rodney Young; SH – Skippy Hau; TS – Troy Shimoda; VG – Vince Goo

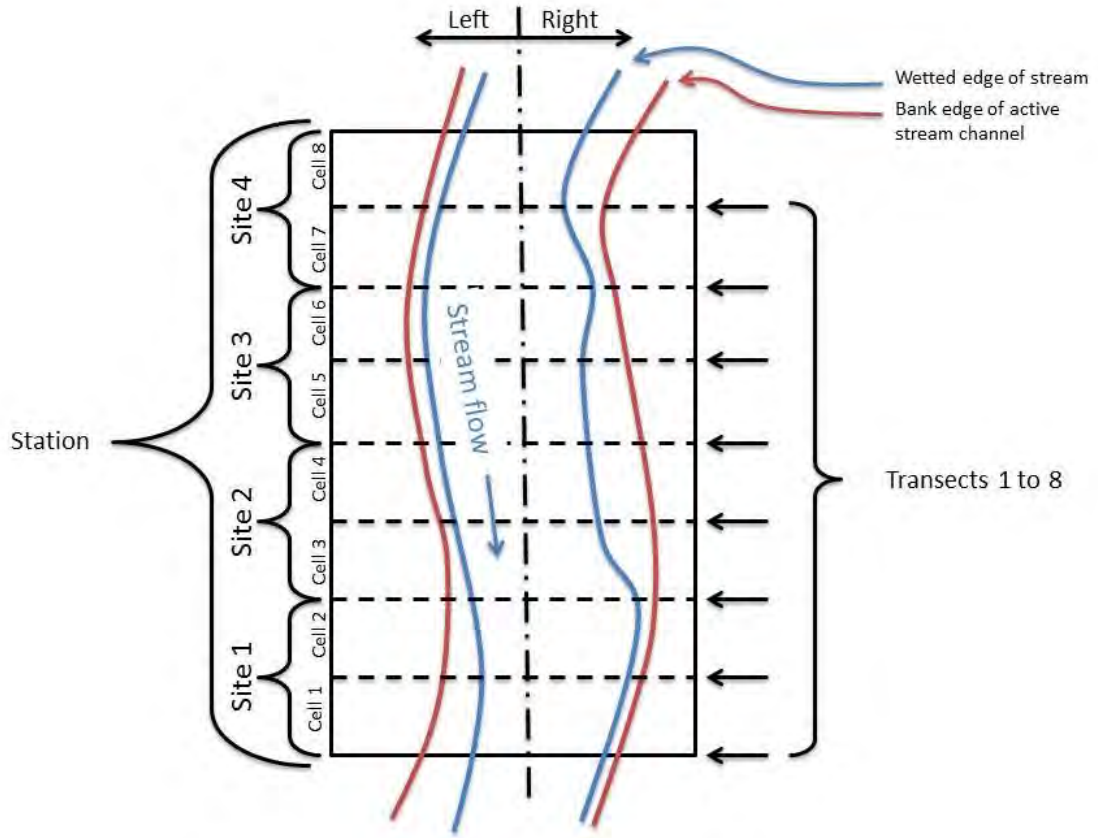


Figure 5: Idealized example of the sampling design showing Station, Site, Cell, and Transect organization with respect to active stream channel, wetted stream width, and orientation of right and left bank.

General Station characteristics:

At the upper station boundary, stream discharge was determined by recording water depth and velocity in segments across the stream channel using a Marsh McBirney 2000™ flow meter in conjunction with a top setting wading rod which can set the flow sensor at 20%, 60%, or 80% of the total depth. The presence of barriers to instream migration, either man-made or natural, were noted during the survey and recorded as impediments to upstream or downstream migration. If weirs or diversions were present, potential upstream or downstream entrainment of the stream animals were also noted.

Habitat Assessment (transects):

At each transect line the active channel width, stream width at the wetted edge, and maximum depth were recorded. Using the transect line as a guide, the percentages of substrate types, (sediment, sand, gravel, cobble, boulders, bedrock, concrete), habitat types (run, riffle, pool, side pool, standing water, dewatered), and organic materials were recorded. In each site, at the lower transect line, the position was saved to a Garmin GPSmap76S™ and the waypoint and coordinates, in decimal degrees, were entered onto the datasheet. Water quality data (temperature, dissolved oxygen, pH, and specific conductivity) were collected using a Hach Quanta Hydrolab™ in the stream channel at this lower transect within each site. Digital images were also collected at each site looking both up and downstream and left bank and right bank.

Habitat Assessment (cells):

Habitat assessment within cells varied depending on which metric was being measured. Bank Vegetative Protection, Riparian Vegetative Zone Width and Bank Stability were measured separately for each stream bank while Embeddedness, Sediment Deposition and Channel Alteration were measured for right and left halves of the stream channel. These habitat parameters were assigned a score which reflected habitat quality and recorded as optimal, suboptimal, marginal, or poor. To assure consistency among surveyors and among survey trips, a copy of the condition categories and their scoring criteria were carried by each surveyor and used as a reference guide. For more detailed information on the above metrics see Chap. 5 (part B): Habitat Assessment and Physicochemical Parameters in the EPA's Rapid Bioassessment Protocols For Use in Streams and Wadeable Rivers (Barbour et al., 1999). Digital images were taken of the sampled sites looking up and downstream (See Appendix 2, 3, 4).

Biotic Surveys:

Visual observations were conducted throughout each individual section by observers using snorkeling gear wherever possible. In extremely shallow areas, above water observations were used. Surveys were conducted in an upstream direction using natural partitions in each site, such as steps, large boulders, etc., to minimize native macrofauna disturbance.

Each of the native amphidromous stream animals observed was counted and its length was estimated into a size class. Six size range classes were used for native stream fauna observed in each site. The categories for the larger sized species ranged from less than or equal to 1 inch to greater than 9 inches for *Lentipes concolor, Stenogobius hawaiiensis, Sicyopterus stimpsoni, Awaous stamineus, Eleotris sandwicensis,* and the crustacean *Macrobrachium grandimanus*. The smaller sized fauna is comprised of two mollusks, *Neritina granosa, Neritina vespertina* and the crustacean *Atyoida bisulcata* and their sizes ranged from less than or equal to one quarter of an inch to greater than one and one half inches. Marine native and/or introduced species observed in each site were assigned an abundance score, such as P=present (1-9), C=common (10-19), and A=abundant (20+) according to the number seen at each site.

Analytical Methods:

The focus of the monitoring effort was to determine if the return of water had an effect on the habitat and abundance of native stream animals. As a result, the analysis of the data focused on three broad areas: (1) changes in physical habitat, (2) changes in stream biota, and (3) the presence of connectivity between the lower and upper stations.

Given the naturally variable conditions and populations within Hawaiian streams and the fact that we did not have long-term monitoring stations established prior to the water returns, most comparisons described here are descriptive and based on average conditions observed over time at each station. In addition to looking at the average change over time, the winter (larger water returns) and summer (lower water returns) were highlighted in each comparison.

Changes in Habitat

For each station, measurements of individual habitat variables were averaged and then plotted to observe changes over time. The pattern of change was compared between the lower and upper stations on a stream to see if consistent changes were observed. We also compared digital images of the sites over time to see if the measured or other changes were apparent in the images.

Changes in Biota

Two questions were addressed when observing the results of the species data. First, were small animals recruiting to the area? If small individuals were recruiting, the second question asked was, were the animals growing and becoming more common in the area? To answer this question we looked at the distribution of individuals within size classes to see if more animals and larger animals were present over time.

Changes in Connectivity

For species that were expected to occur in the upper stream stations, we looked at the presence of small animals to see if they occurred more frequently post water return. If so, then connectivity was likely improved by the water returns.

Results:

Changes in Habitat

East Wailua Iki: Lower Station

(Figures 6 to 14)

A cobble berm found at the mouth of the stream caused the water to impound and form a large pool. The pool formed by the berm at the lower East Wailua Iki monitoring station's habitat was observed at the site during each survey period. The berm was permeable to sea water (confirmed by salinity readings on a Hydrolab MS) and as a result, the water surface elevation within the pool was affected by changes in tidal stage. The East Wailua Iki lower station was the only station where stream flow was not measured as a result of the stream mouth being closed by the berm. No clear relationship between discharge, depth, and width was observed and may have been obscured by the tidal effects. Specifically, the Average Channel Width showed no changes during the sampling period. The Average Max Depth & Average Wetted Width did vary, but from field observations the changes appeared to be more closely related to the tidal stage than to discharge. The recorded changes in Habitat Type, moving from standing water to pool type habitat, is likely not reflective of a change in habitat, but rather a discrepancy in how the Habitat Type was coded. In all cases, the site was a large pool with standing water as a result of the stream-mouth berm.

For the substrate observed, there were some changes over time, but these changes were probably not related to the small changes in released water. The changes in substrate showed a small increase in small and fine substrates over time. This would be suggestive of lower stream power over time. As stream flow, and closely related stream power, increases, the water has the ability to transport medium and large substrate classes. In general, substrate composition is controlled more by high flow events and as a result, small changes in substrates likely reflect the time since that last high flow event as opposed to a water return indicator.

Shoreline measures including Average Bank Vegetation Protection, Average Riparian Vegetative Zone, and Average Bank Stability showed very little difference with scores reflecting generally high quality habitat conditions.

Overall, winter flow restoration appeared to have little impact on physical habitat. In general, most of the physical parameters measured provided good conditions for stream animals. Little change in any of the physical parameters observed is likely a result of a large pool being created by the stream mouth being closed by the cobble berm during each survey period. Permeability of the cobble berm was apparent at the lower pool sites as visual layering of freshwater was apparent over saltwater and as a result, the water depth varied with changes in tidal stage as well as stream discharge. The growth of thick mats of green algae was common on the bottom of the lower site and indicative of the brackish water conditions. The amount of water return mandated in the IIFS for East Wailua Iki Stream in either the winter or summer is unlikely to substantially improve the amount of native stream animal habitat.

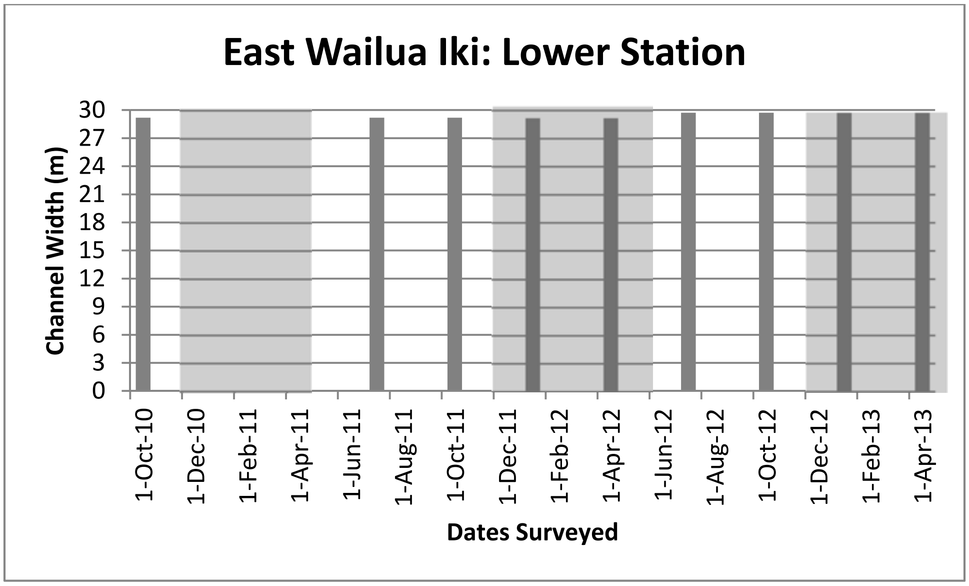


Figure 6. Average channel width in the Lower Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

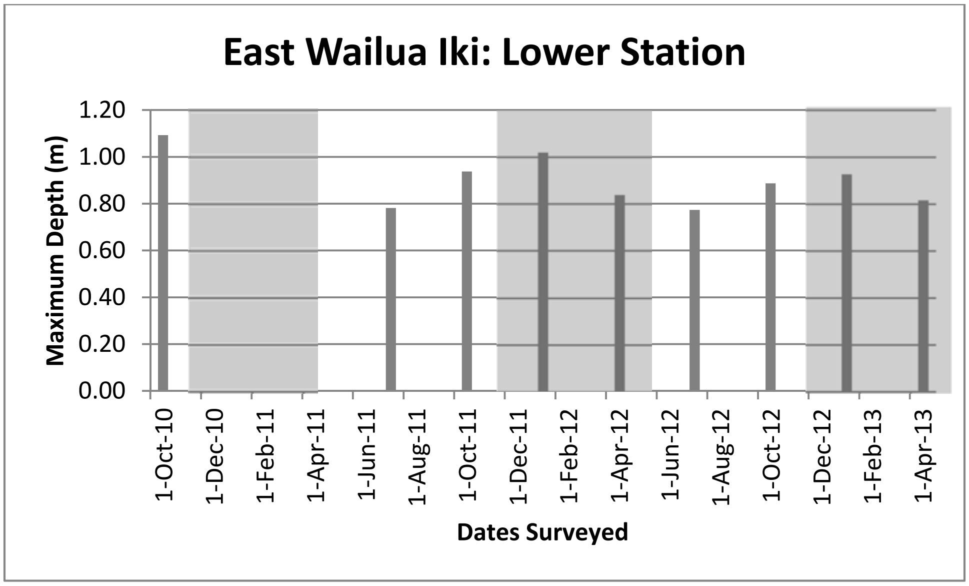


Figure 7. Average maximum stream depth in the Lower Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

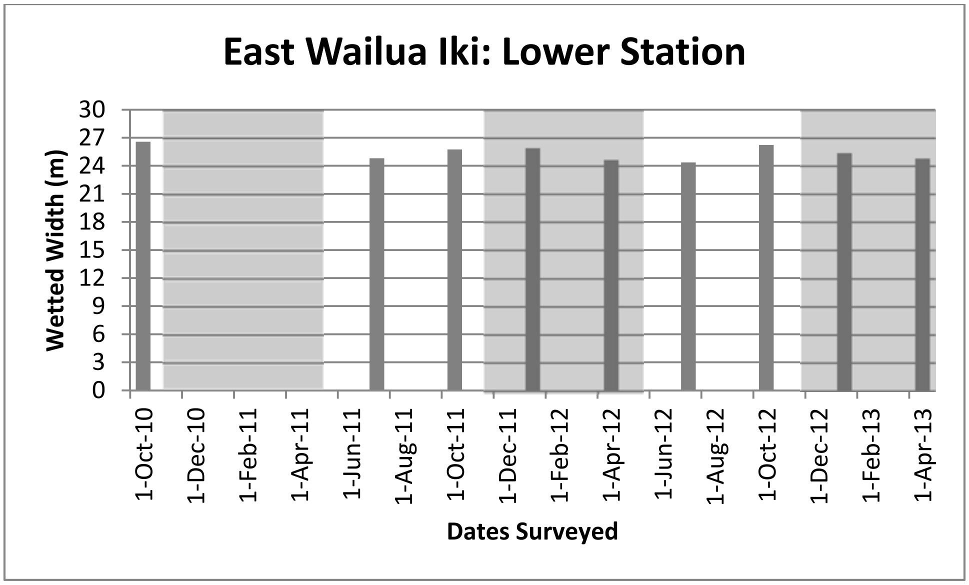


Figure 8. Average wetted width in the Lower Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

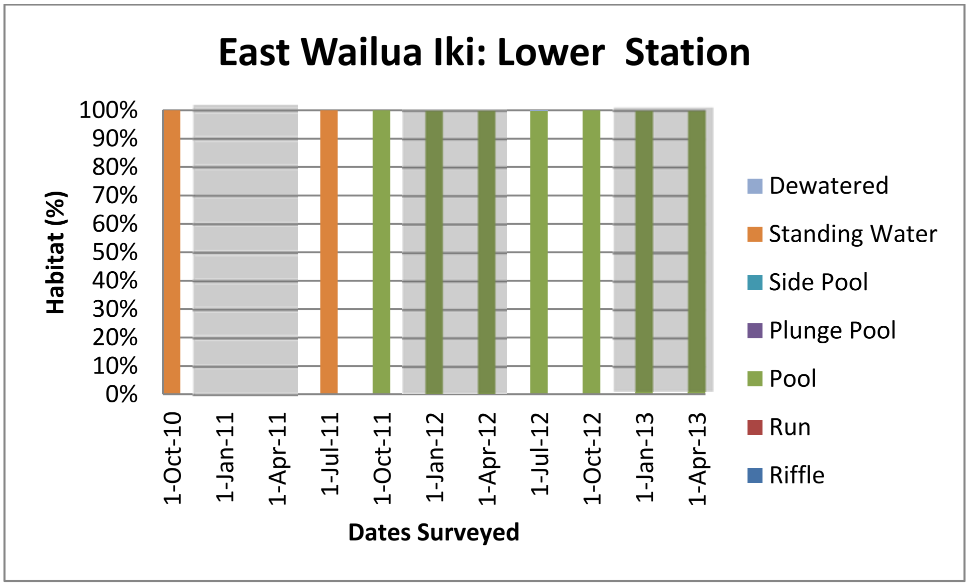


Figure 9. Habitat type by survey date for the Lower Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

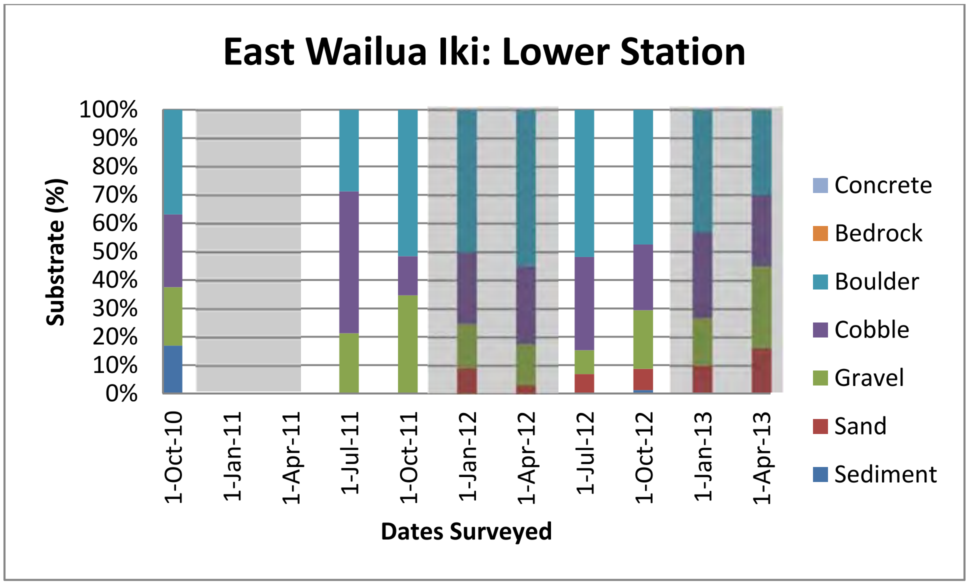


Figure 10. Substrate type by survey date for the Lower Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

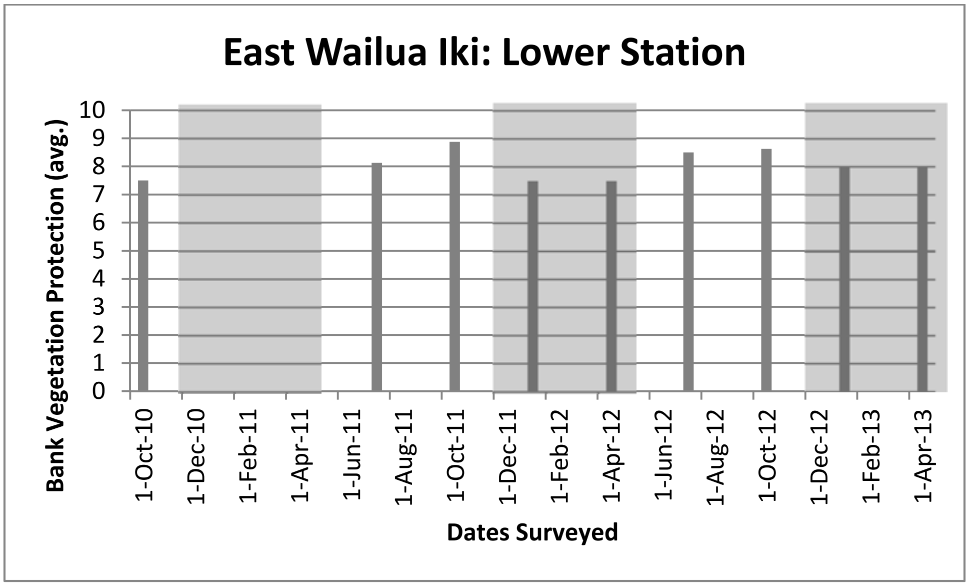


Figure 11. Average bank vegetation protection in the Lower Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

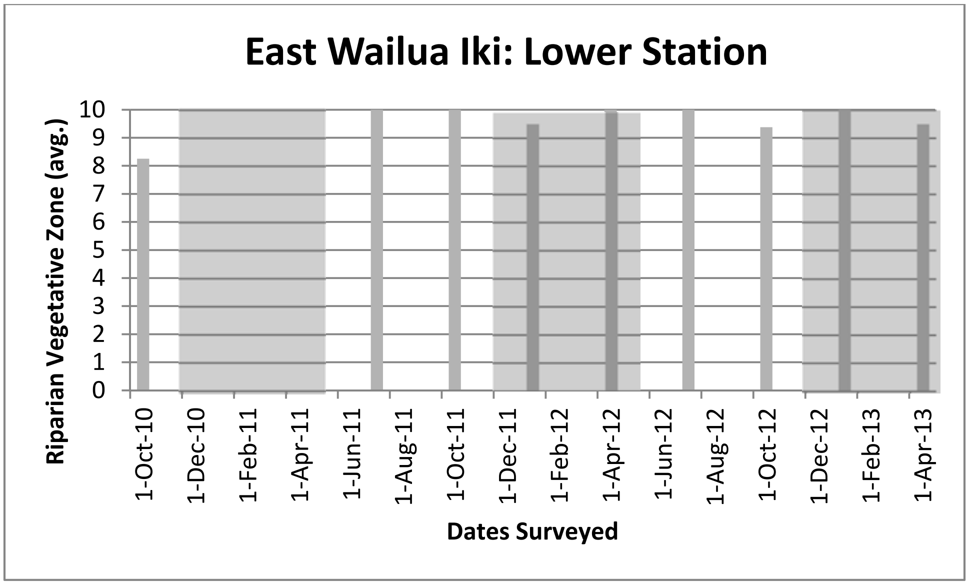


Figure 12. Average riparian vegetative zone in the Lower Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

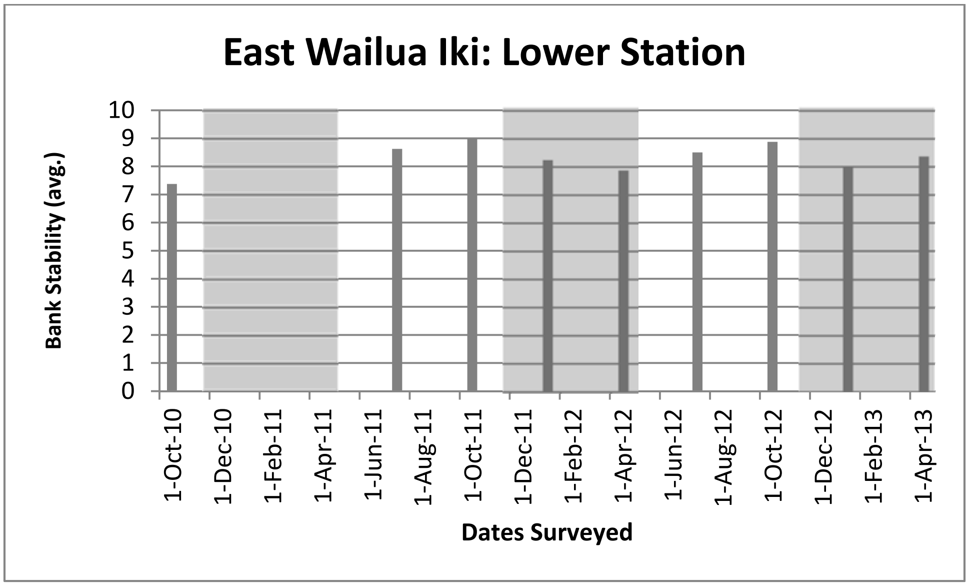


Figure 13. Average bank stability in the Lower Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.


1. Gate Closed 10/19/10 Flow: nm


2. Water Release 1/25/12 Flow: nm


3. Water Release 4/11/12 Flow: nm


4. Gate Closed 7/11/12 Flow: nm


5. Gate Closed 10/11/12 Flow: nm


6. Water Release 1/30/13 Flow: nm

7. Gate Closed 4/24/13 Flow: nm

Figure 14. East Wailua Iki, Site 1 upstream view during different survey dates and water releases. Flow nm = not measured.

East Wailua Iki: Upper Station

(Figures 15 to 23)

For the upper station on East Wailua Iki Stream, we observed some changes that would suggest that instream habitat was improved by the winter flow restorations. Habitat Types observed showed a decrease in standing water, side pools, or dewatered areas during the winter periods with flow releases when compared to the summer periods. The increased winter flow as a result of the water return may have positively affected instream habitat toward a more flowing stream-like condition. When we observed the digital images of these sites over time, winter flows appeared to show higher velocities and more connectivity than conditions during other periods.

Unlike the patterns observed in Habitat Type and in the digital images, Average Channel Width showed no changes during the sampling period. Additionally, the measures of Average Max Depth and Average Wetted Width showed deeper depths and greater widths over time, but this pattern did not correlate strongly to the winter flow return periods.

Substrate in the upper station was dominantly boulder and bedrock substrates in all surveys and there was little change over time related to the flow restoration periods. This is not surprising as the distribution of cobble, boulder, and bedrock substrates are controlled more by flood flows than low flows. Very little difference was observed for the Average Bank Vegetation Protection, Average Riparian Vegetative Zone, and Average Bank Stability with scores reflecting generally high quality habitat conditions.

In general, most of the physical parameters measured provided good conditions for stream animals. This upper station is characterized by large plunge pools and appeared to provide suitable habitat for stream animals. Overall, winter flow restoration appeared to have had a positive impact on improving stream-like conditions in upper East Wailua Iki. However, some of the variability in the results may have been the result of rainfall prior to some of our sampling trips.

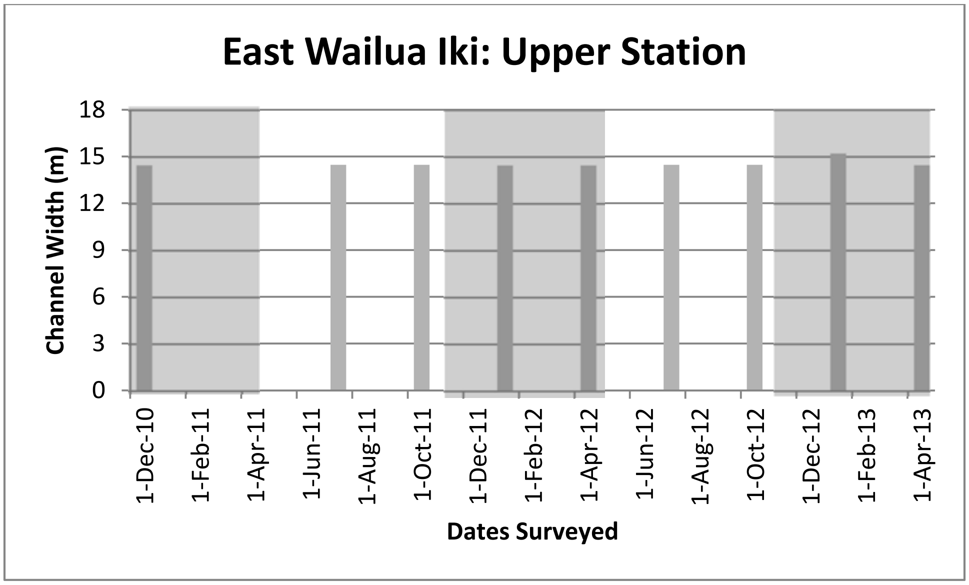


Figure 15. Average channel width in the Upper Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

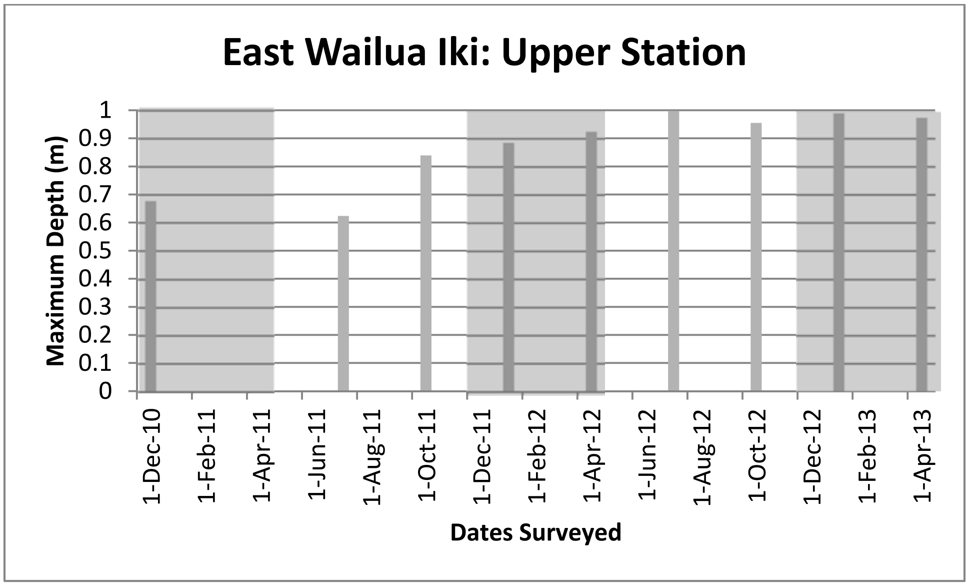


Figure 16. Average maximum stream depth in the Upper Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winters.

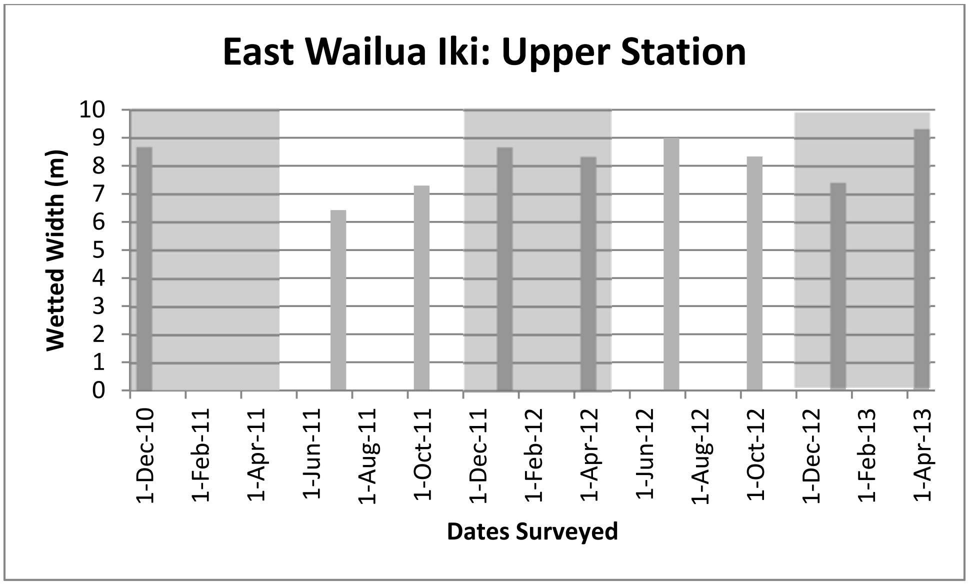


Figure 17. Average wetted width in the Upper Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

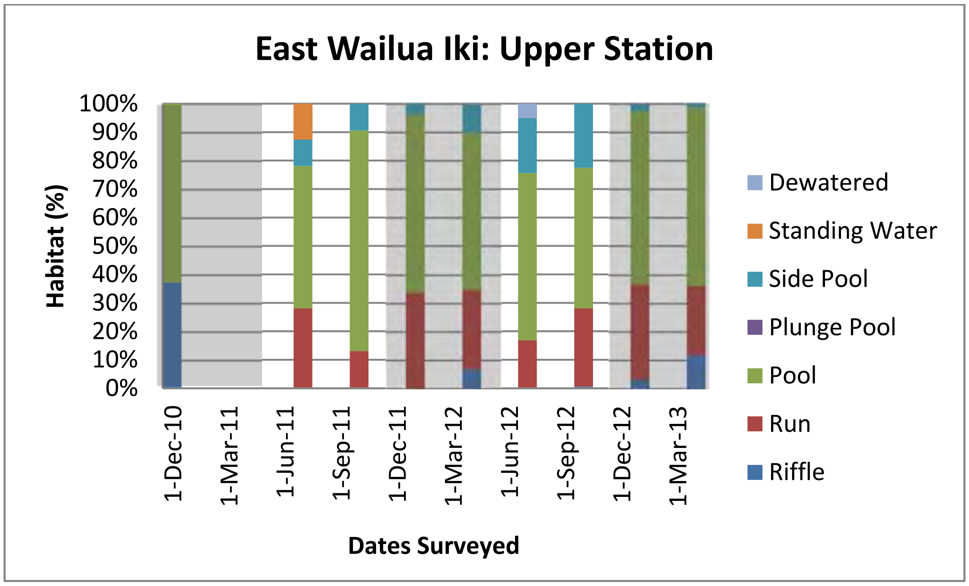


Figure 18. Habitat type by survey date for the Upper Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter

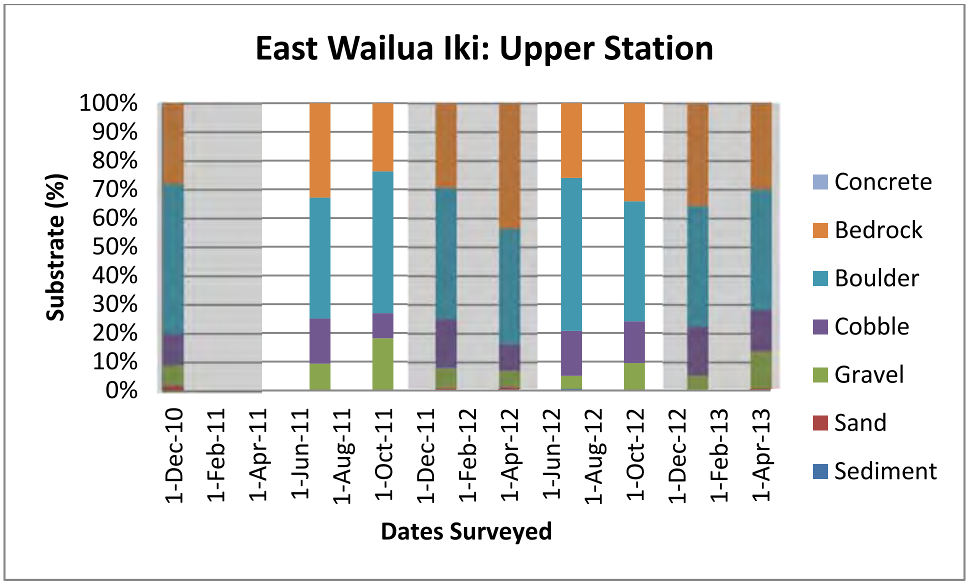


Figure 19. Substrate type by survey date for the Upper Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

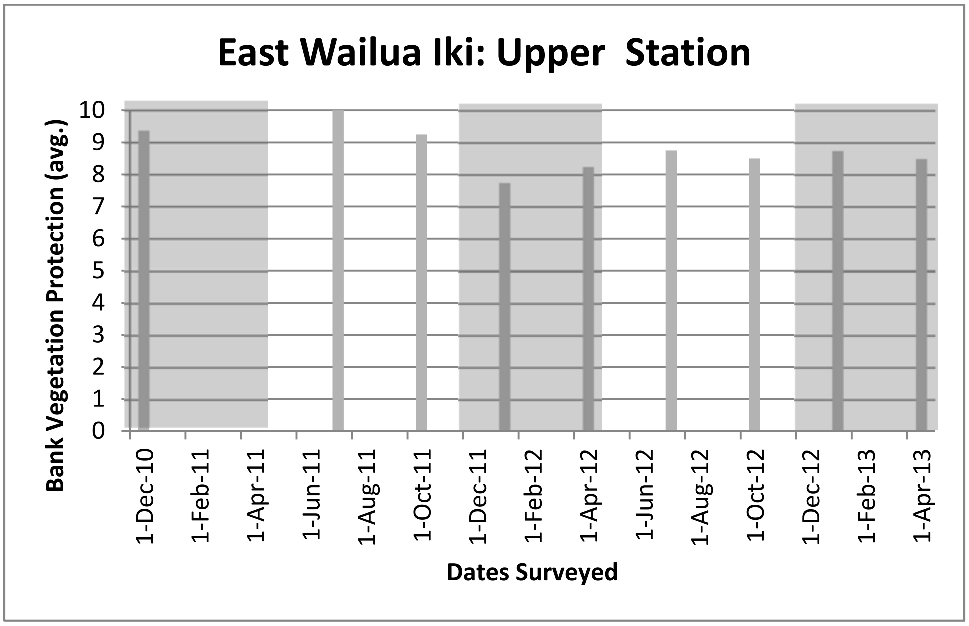


Figure 20. Average bank vegetation protection in the Upper Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

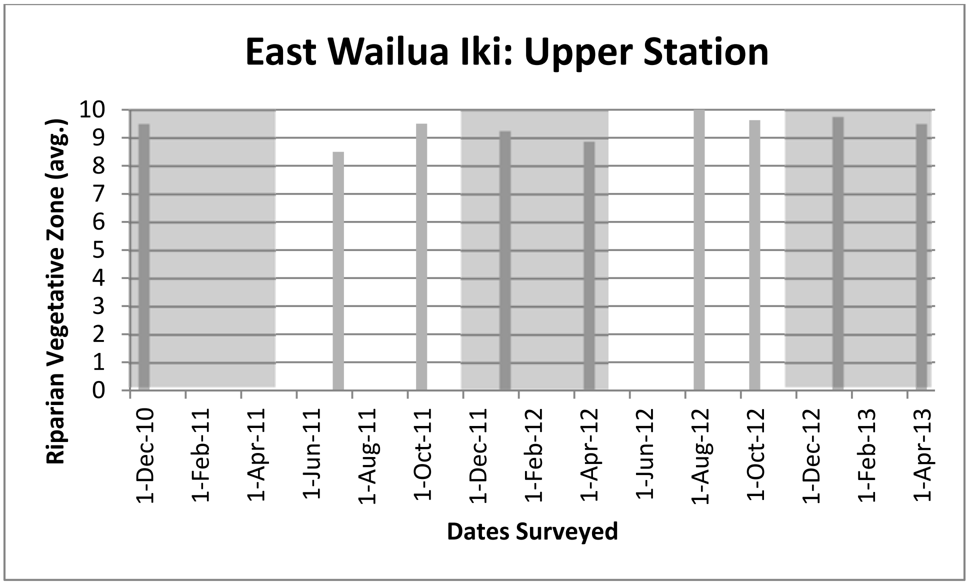


Figure 21. Average riparian vegetative zone in the Upper Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

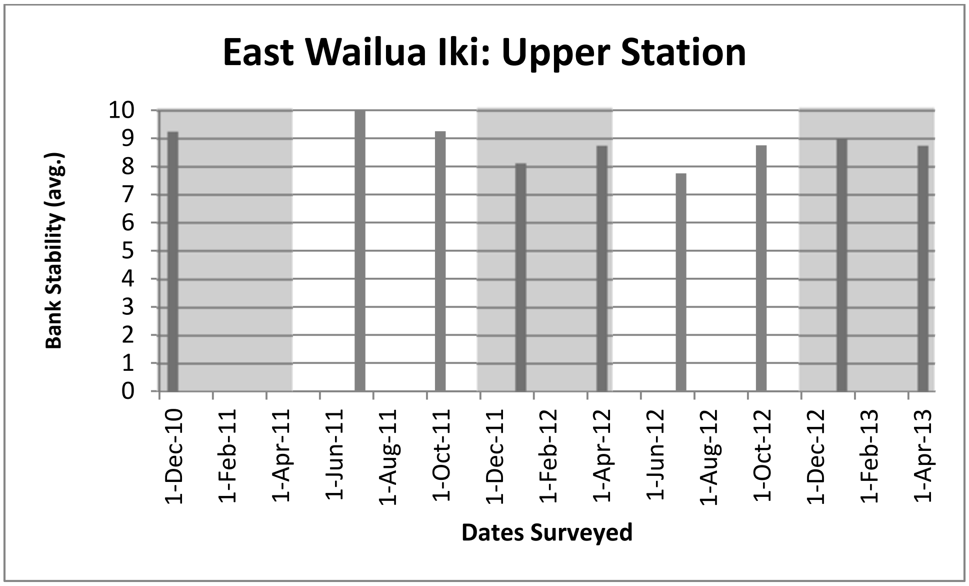


Figure 22. Average bank stability in the Upper Station of East Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

1. Pre-water Release 12/2/10 Flow: -0.01 cfs

2. Water Release 1/24/12 Flow: 2.57 cfs

3. Water Release 4/13/12 Flow: 3.06 cfs

4. Gate Closed 10/10/12 Flow: 0.78 cfs

5. Water Release 1/29/13 Flow: 2.54 cfs

6. Water Release 4/23/13 Flow: 2.64 cfs

Figure 23. Digital Images of the upstream view of Site 4 on upper East Wailua Iki during different survey dates and water releases.

West Wailua Iki: Lower Station

(Figures 24 to 32)

Changes observed in the lower West Wailua Iki Stream monitoring station were inconclusive. There were substantial changes in habitat over the sampling period although the changes were not easily correlated to changes in flow restoration timing. The station appeared to have many dewatered and pooled water sections in the first years of the surveys, but this was replaced by runs and riffles in the second half of the surveys. It is possible that this was due to the winter and summer flow restoration, but it is not a clear pattern. Some of the digital images of the sites showed higher flows and more connectivity during winter release periods although some images showed lower flow and less connectivity during winter release periods.

Like the lower station on East Wailua Iki Stream, the Average Channel Width showed little change during the sampling period, while the Average Max Depth and Average Wetted Width appeared to be more closely related to the increase over time and possibly with winter flow restoration. The station was composed mostly of boulder and cobble substrates in all sample periods and there was little change observed in substrate over time.

Like most of the monitoring stations, very little difference was observed for the Average Bank Vegetation Protection, Average Riparian Vegetative Zone, and Average Bank Stability with scores reflecting generally high habitat quality conditions.

Overall, winter flow restoration did not appear to have a clear impact on the physical parameters measured. It is likely that rainfall events prior to the monitoring survey dates may have obscured the impact of flow restoration on observed stream conditions, especially during the summer survey periods. Given the variability of conditions, winter flow restoration may have a positive impact on the instream conditions in lower West Wailua Iki, but summer flow amounts are likely too small to have a large benefit.

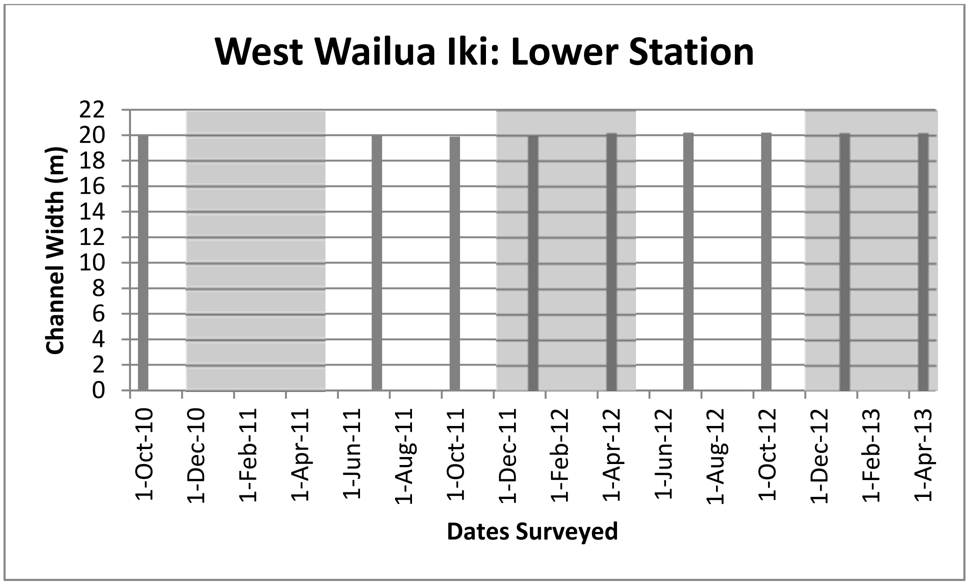


Figure 24. Average channel width in the Lower Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

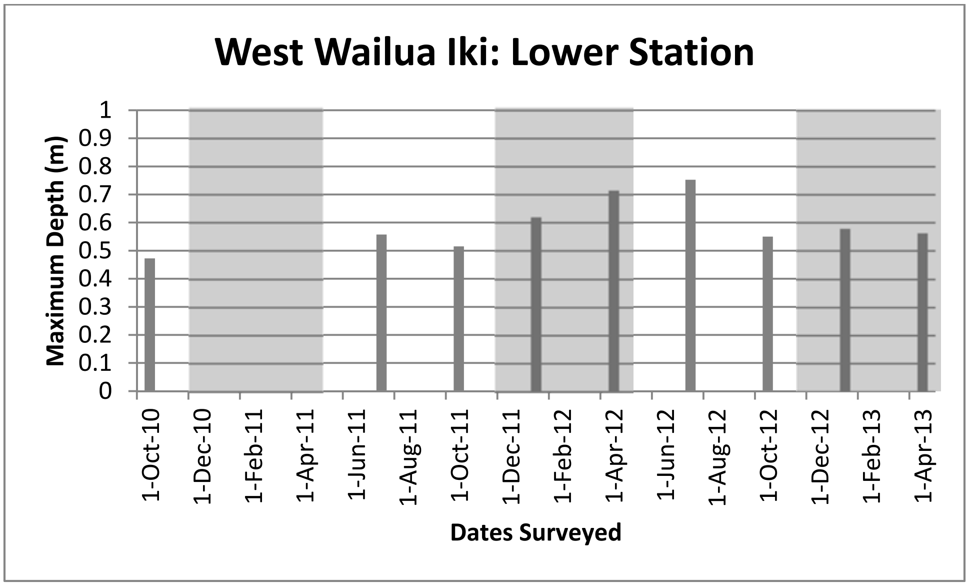


Figure 25. Average maximum stream depth in the Lower Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

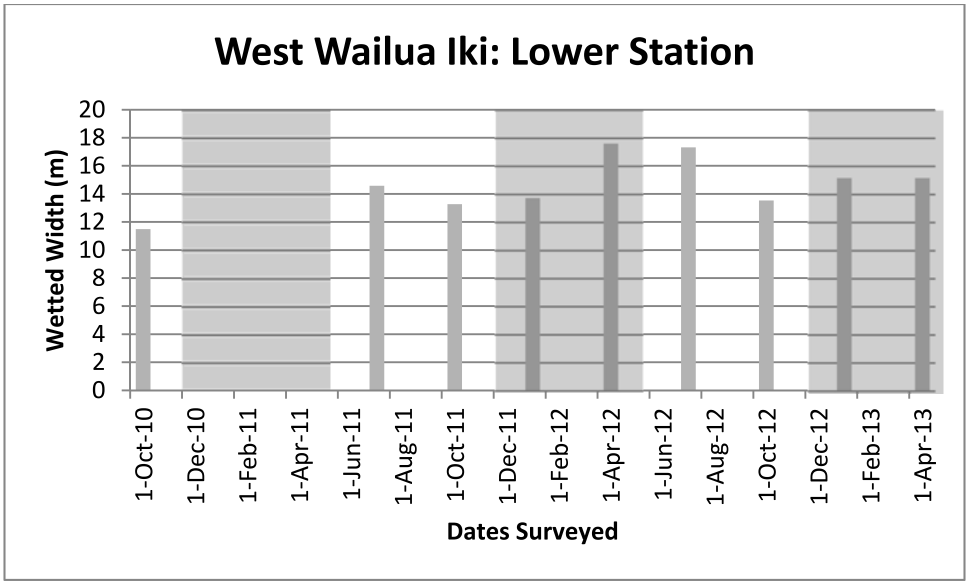


Figure 26. Average wetted width in the Lower Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

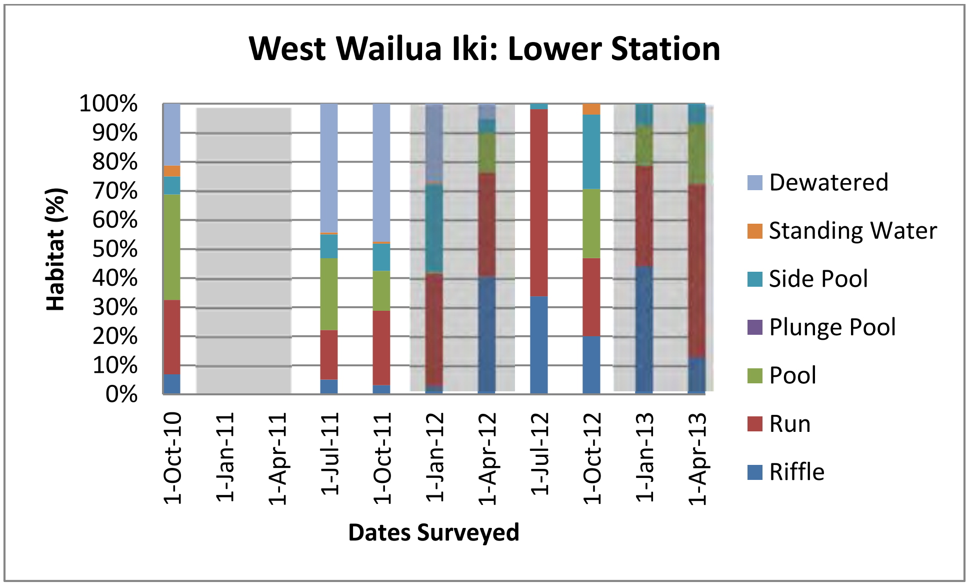


Figure 27. Habitat type by survey date for the Lower Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

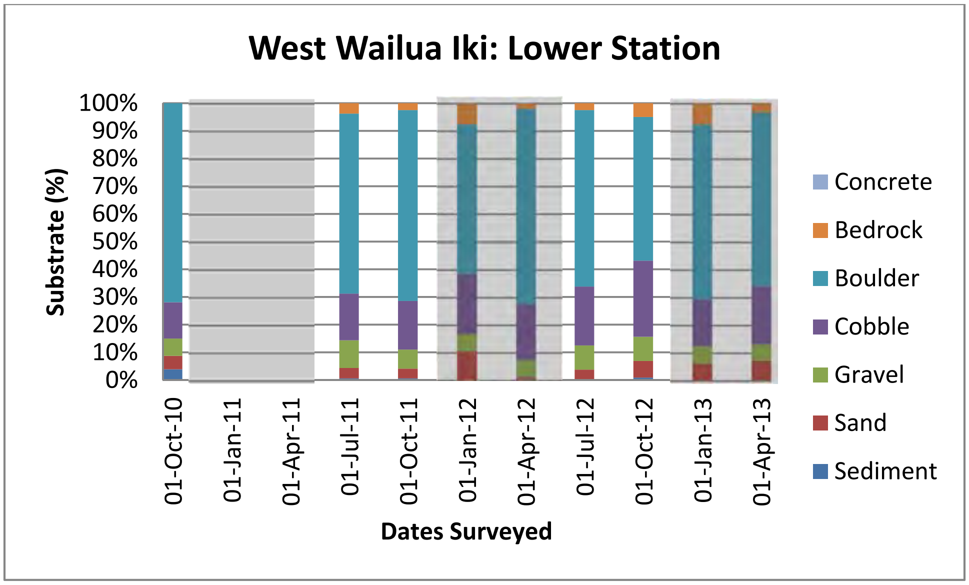


Figure 28. Substrate type by survey date for the Lower Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

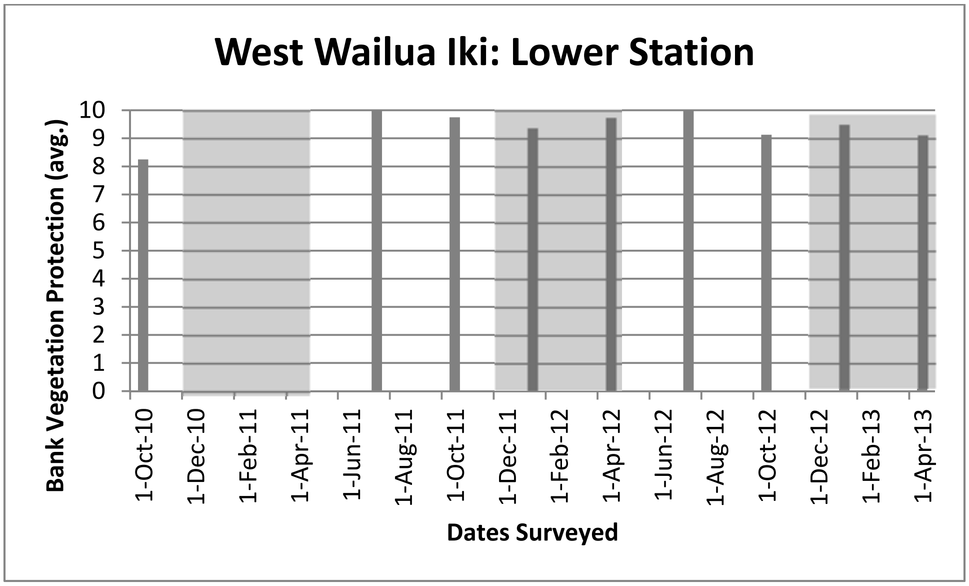


Figure 29. Average bank vegetation protection in the Lower Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

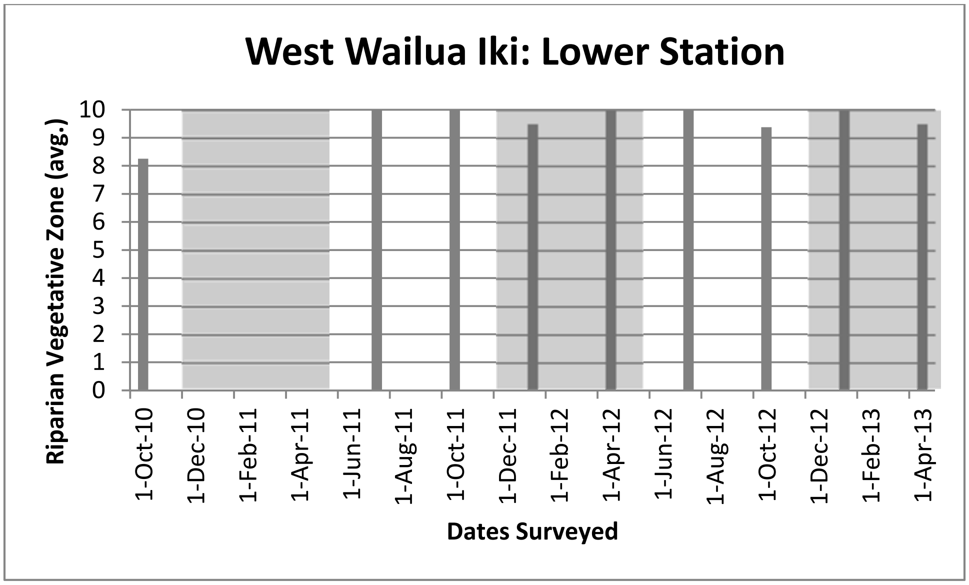


Figure 30. Average riparian vegetative zone in the Lower Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

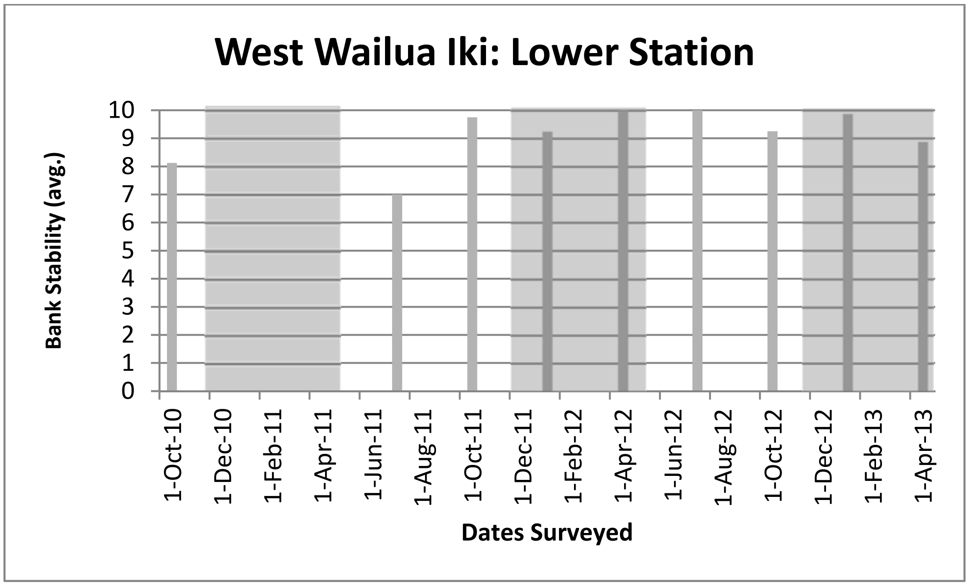


Figure 31. Average bank stability in the Lower Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

1. Pre-water Release 10/19/10 Flow:0.36 cfs

2. Water Release 1/25/12 Flow: 2.27 cfs

3. Water Release 4/11/12 Flow: 10.86 cfs

4. Gate Closed 10/11/12 Flow: 0.77 cfs

5. Water Release 1/30/13 Flow: 1.95 cfs

6. Gate Closed 4/24/13 Flow: 1.88 cfs

Figure 32. West Wialua Iki digital images of Site 2 upstream view during different survey dates and water releases.

West Wailua Iki: Upper Station

(Figures 33 to 41)

For the upper station on West Wailua Iki stream, we observed some changes that may reflect improvements in stream habitat with respect to the mandated flow restoration, but changes were not entirely consistent. The sites appeared to have many dewatered sections in the summer period prior to water restoration, but this pattern was not observed during summer flow restoration periods in later samples. Winter samples with restored flows had similar habitat type composition to summer flow restored conditions. The sites were composed mostly of bedrock substrate in all sample periods and although some variability in substrate composition was observed over time, but unlikely related to flow restoration.

Station measure for Average Channel Width showed no changes during the sampling period, while those for Average Max Depth and Average Wetted Width showed some difference observed but these differences did not correlate to flow releases. Wetted width changed markedly among survey trips ranging from under 5 ft to over 14 ft in subsequent surveys. It is unclear why the wetted width changed so dramatically among samples. These changes may have been a result of small changes in transects locations which relocated width measures from narrow riffles to wide plunge pools.

Very little difference was observed for the Average Bank Vegetation Protection, Average Riparian Vegetative Zone, and Average Bank Stability with scores reflecting generally high quality habitat conditions.

Overall, this upper station is characterized by large plunge pools and appeared to provide suitable habitat for stream animals. The digital images of the sites show an improvement in winter flow connectivity although direct measures do not show this clearly. In general, most of the physical parameters measured provided good conditions for stream animals. As with most sites, the presence or absence of prior rainfall may greatly affect observed conditions. Even so, it does still appear that IIFS winter flow amounts improve instream conditions.

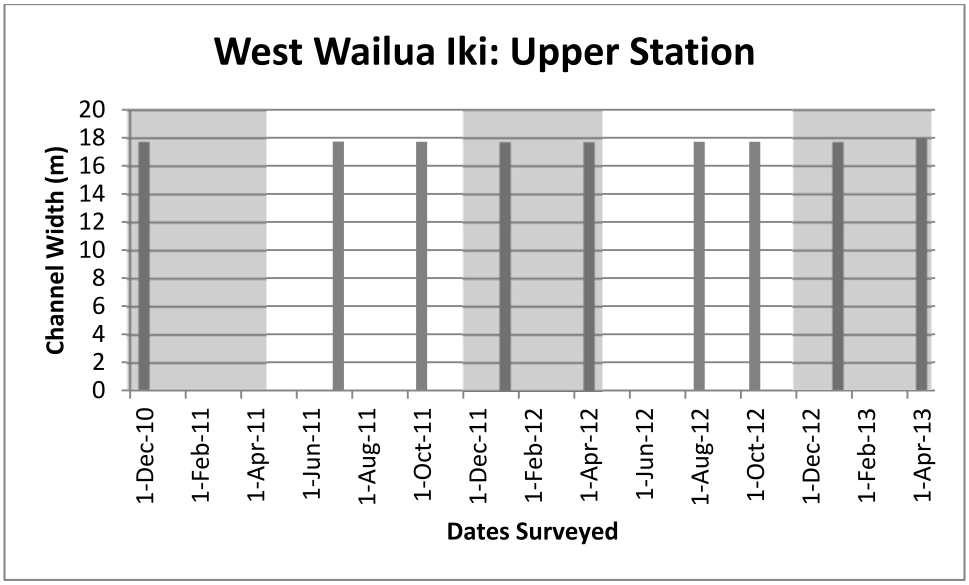


Figure 33. Average channel width in the Upper Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

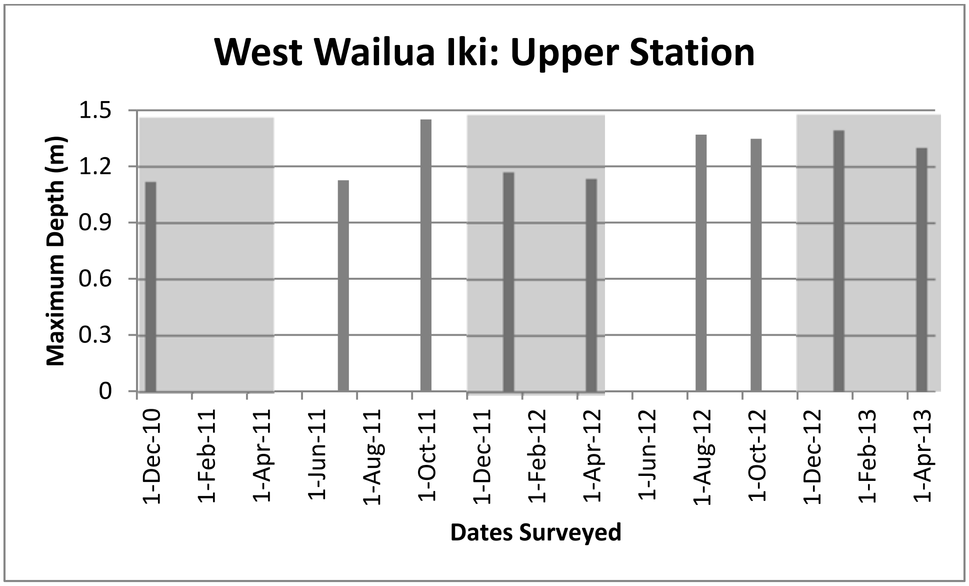


Figure 34. Average maximum stream depth in the Upper Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

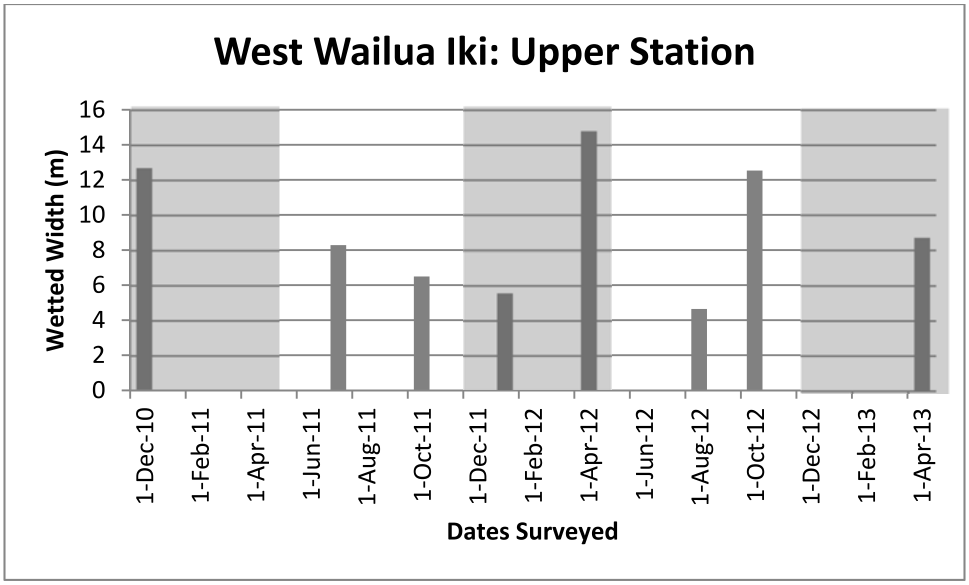


Figure 35. Average wetted width in the Upper Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

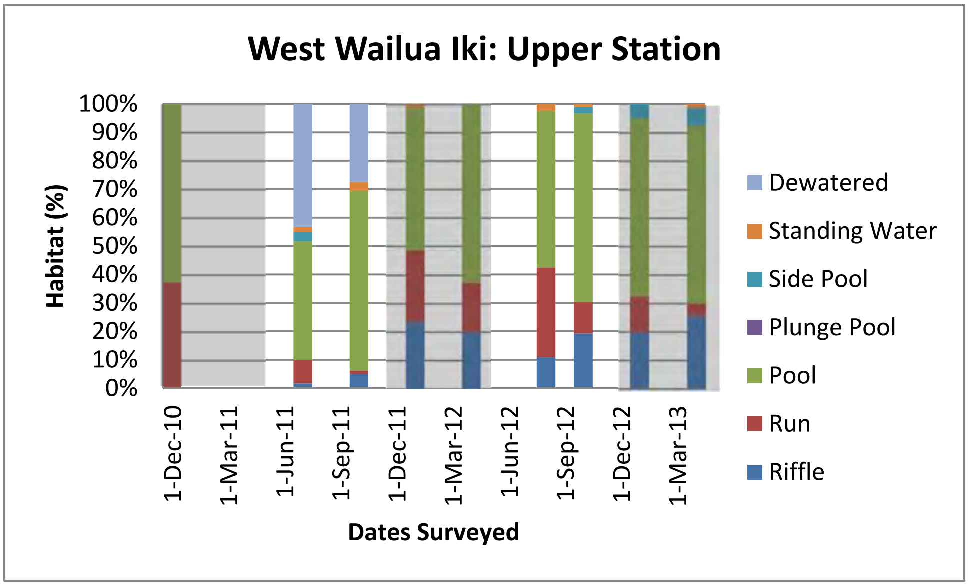


Figure 36. Habitat type by survey date for the Upper Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

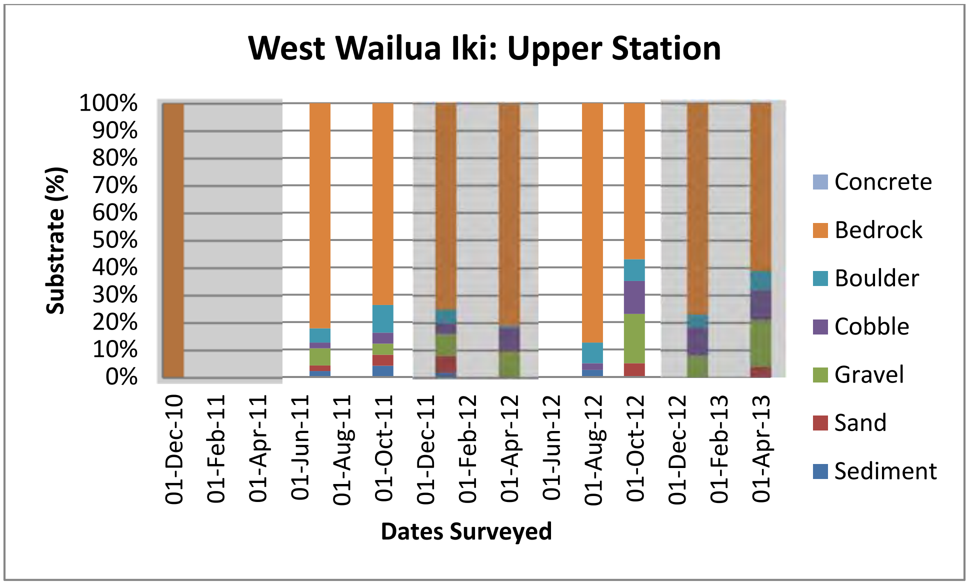


Figure 37. Substrate type by survey date for the Upper Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

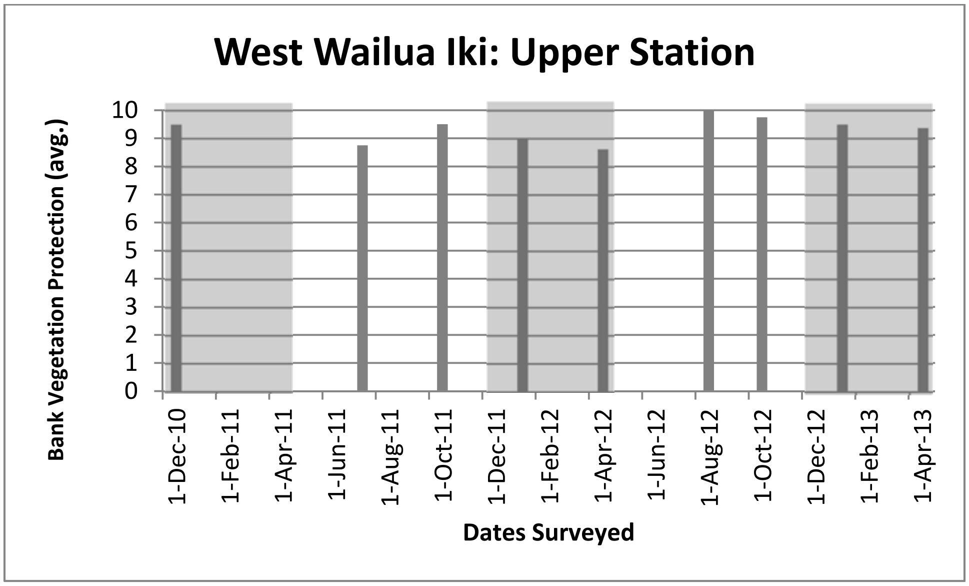


Figure 38. Average bank vegetation protection in the Upper Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

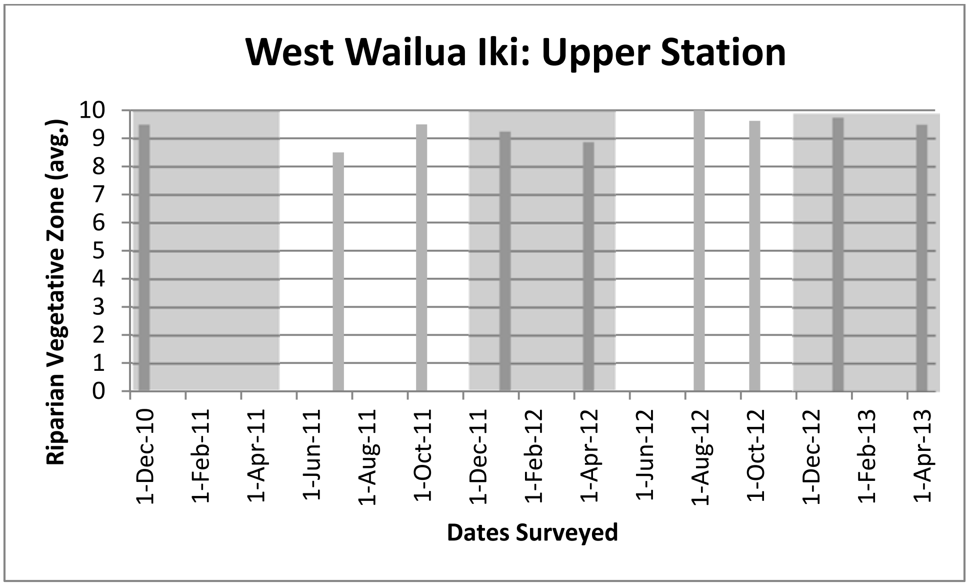


Figure 39. Average riparian vegetative zone in the Upper Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

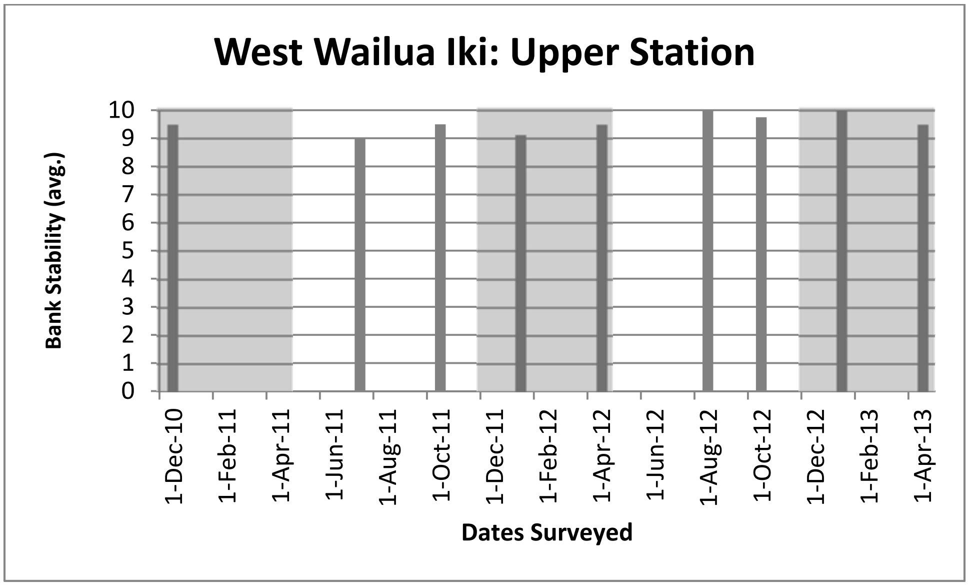


Figure 40. Average bank stability in the Upper Station of West Wailua Iki. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

1. Pre-water Release 12/02/10 low: 0.18 cfs

2. Water Release 1/24/12 Flow: 1.28 cfs

3. Gate Closed 8/7/12 Flow: 0.19 cfs

4. Gate Closed 10/10/12 Flow: -0.03 cfs

5. Water Release 1/29/13 Flow: 1.88 cfs

6. Water Release 4/23/13 Flow: 1.94 cfs

Figure 41. Upper Station of West Wailua Iki Site 1 upstream view during different survey dates and water releases.

Waiohue Stream: Lower Station

(Figures 42 to 50)

At the lower Waiohue Stream station, we observed variability in habitat composition over time. The site appeared to have many dewatered sections in the summer period prior to water restoration, but this pattern was not observed during either winter or summer flow conditions in the post-restoration surveys. The site appeared to be in good condition in all of the post-restoration surveys except one. During that one survey, conditions were not suitable for instream observations, as surveyors observed a large amount of sand throughout the site as a result of high surf conditions. Only notes were made on these observations as no formal survey was able to be conducted due to the bad weather conditions.

This station was composed of mostly run and riffle habitats and little change to the Average Channel Width was observed during the sampling period. In general, this site was narrower than the other two lower stream stations surveyed. Average Max Depth and Average Wetted Width varied, but the pattern was not clearly related to the increases or decreases in release flows.

Little variability in substrate composition was observed over time. The station was composed mostly of boulder and cobble substrates in all the sample periods. Also, very little difference was observed for the Average Bank Vegetation Protection, Average Riparian Vegetative Zone, and Average Bank Stability with scores reflecting generally high quality habitat conditions.

Overall, flow restoration may have had an impact on improving stream like conditions, but differences between winter and summer release flows were not obvious. As with the other stations, prior rainfall events may have obscured the flow release patterns.

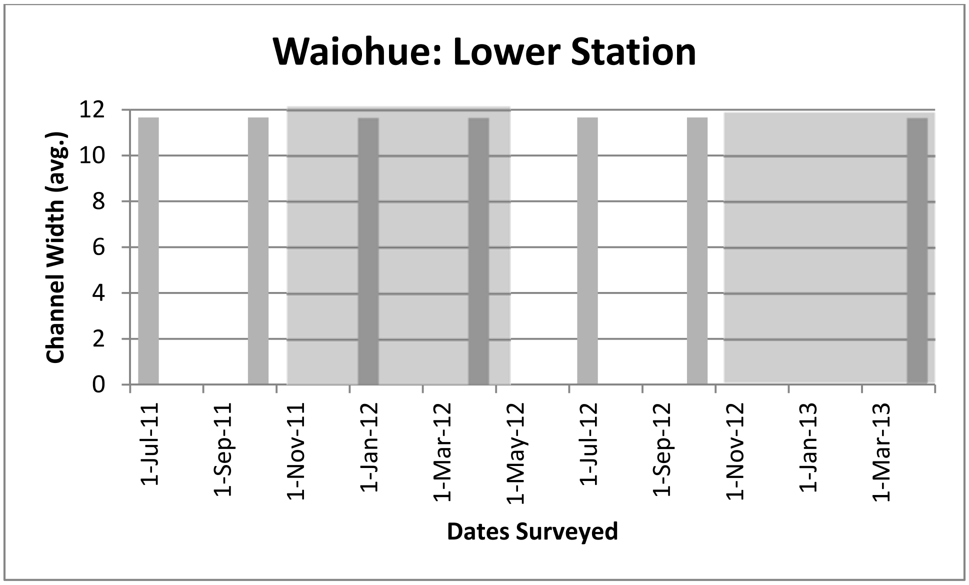


Figure 42. Average channel width in the Lower Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

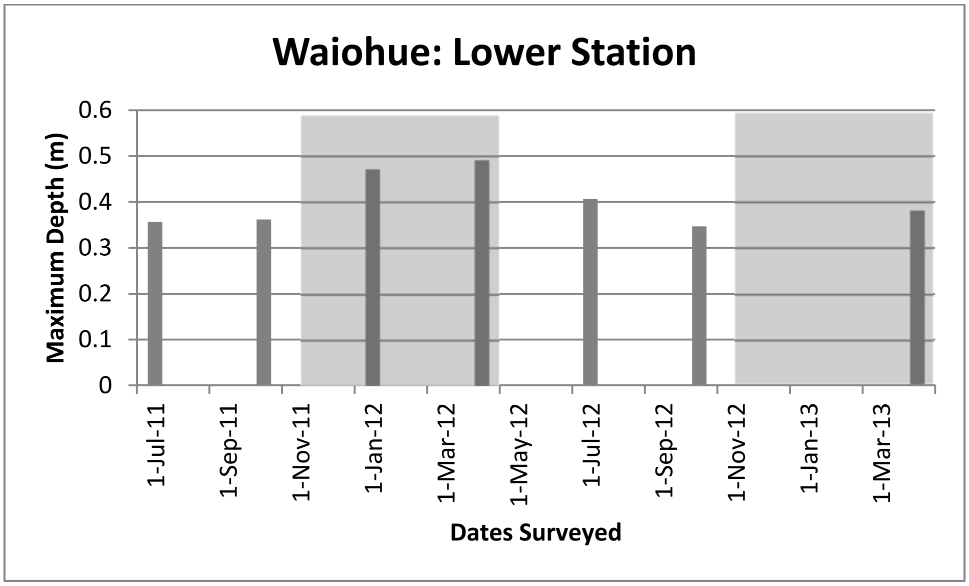


Figure 43. Average maximum stream depth in the Lower Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

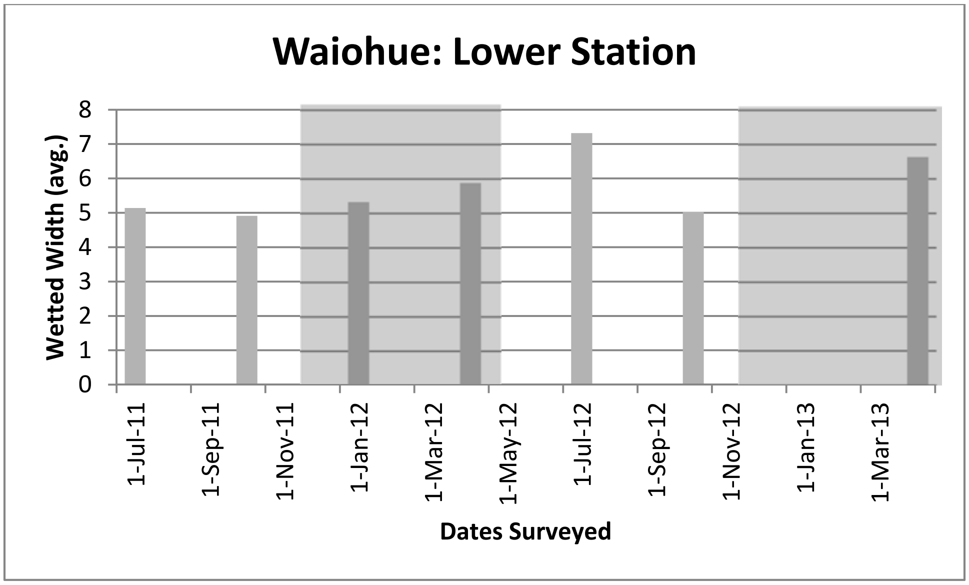


Figure 44. Average wetted width in the Lower Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

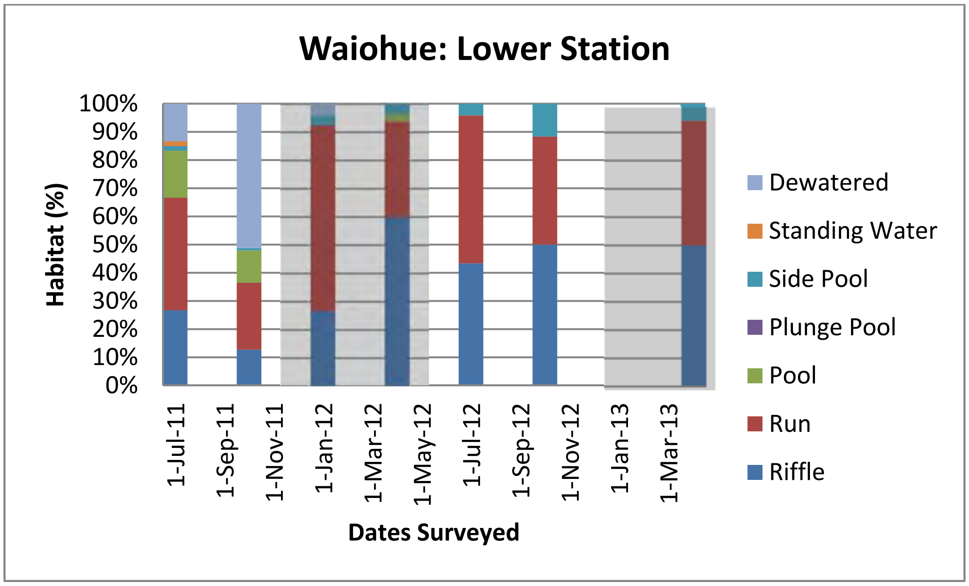


Figure 45. Habitat type by survey date for the Lower Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

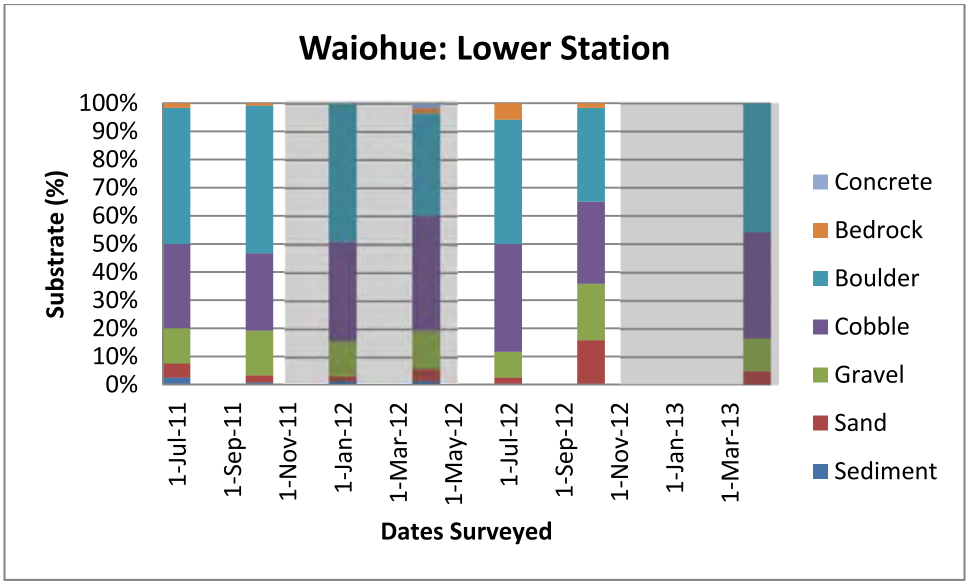


Figure 46. Substrate type by survey date for the Lower Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

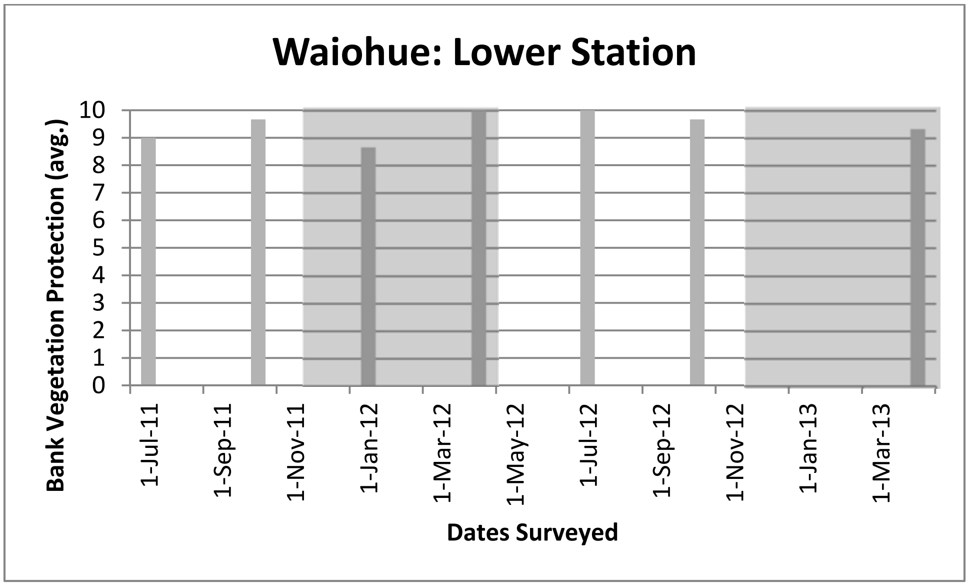


Figure 47. Average bank vegetation protection in the Lower Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

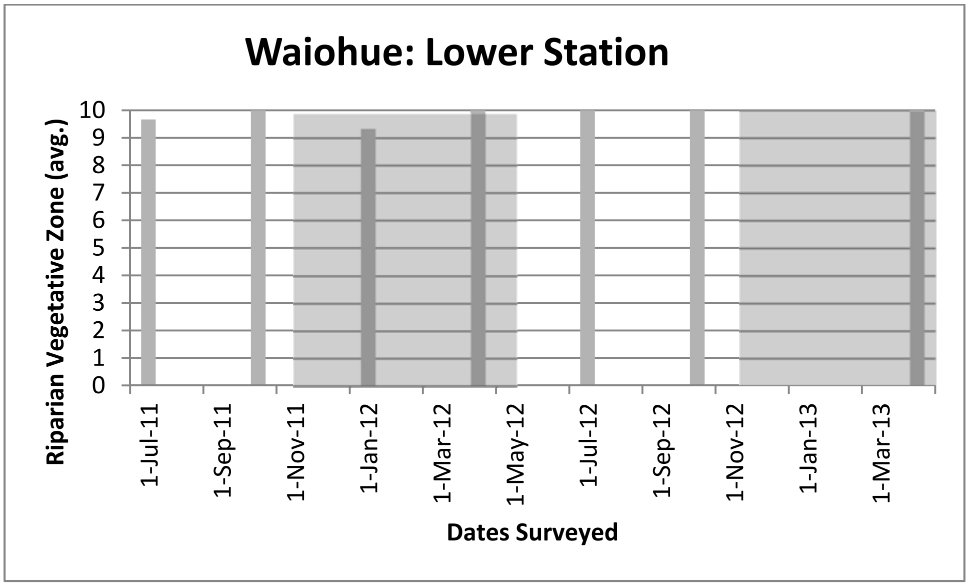


Figure 48. Average riparian vegetative zone in the Lower Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons

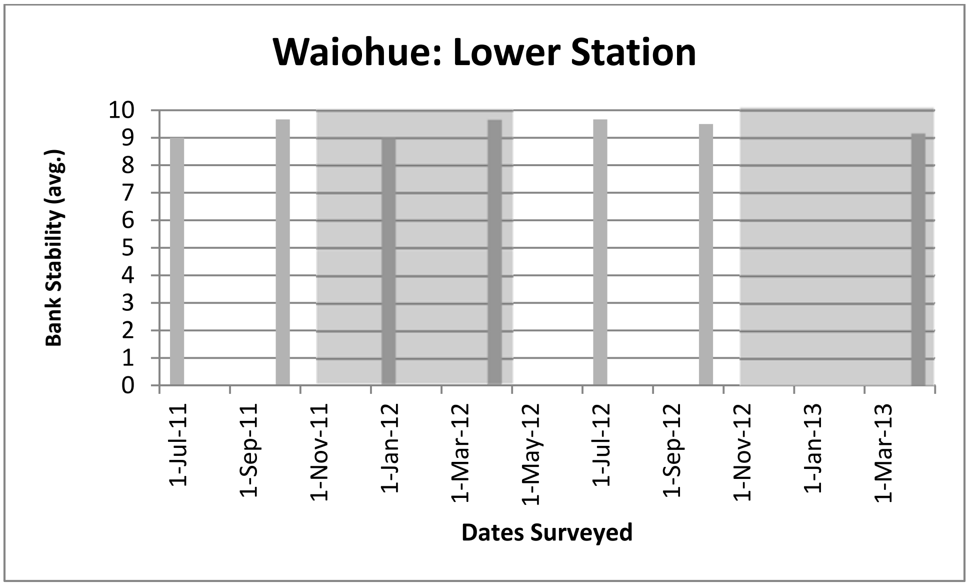


Figure 49. Average bank stability in the Lower Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.


1. Pre-water Release 7/14/11 Flow: 2.26 cfs


2. Water Release 1/26/12 Flow: 3.8 cfs


3. Water Release 4/12/12 Flow: 5.23 cfs


4. Gate Closed 7/12/12 Flow: 1.9 cfs


5. Gate Closed 10/12/12 Flow: 0.85 cfs


6. Water Release 4/25/13 Flow: 3.24 cfs

Figure 50. Lower Station of Waiohue Site 1 upstream view during different survey dates and water releases.

Waiohue Stream: Upper Station

(Figures 51 to 59)

For the upper station on Waiohue Stream, flow restoration and especially winter flow restoration appeared to improve stream-like conditions. During winter releases, run-type habitats were more common and average depth generally increased. We did not observe much change in Average Channel Width, but Average Wetted Width did show differences and possibly weak correlation to flow releases. The changes in summer measures may reflect recent rainfall periods and not flow restoration.

Most other measures showed little change. For substrate a little variability in composition was observed over time. The site was composed mostly of boulder and bedrock substrate in all sample periods. Very little difference was observed for the Average Bank Vegetation Protection, Average Riparian Vegetative Zone, and Average Bank Stability with scores reflecting generally high quality habitat conditions.

Overall, winter flow restoration did improve stream conditions. This station was confined in a narrow stream channel of mostly boulders and bedrock. In general, most of the physical parameters measured provided good conditions for stream animals. From observations, the stream channel above the diversion return gate was normally dry up to the waterfall plunge pool wall. Little or no connectivity was shown between the plunge pool and the diversion site during the water return.

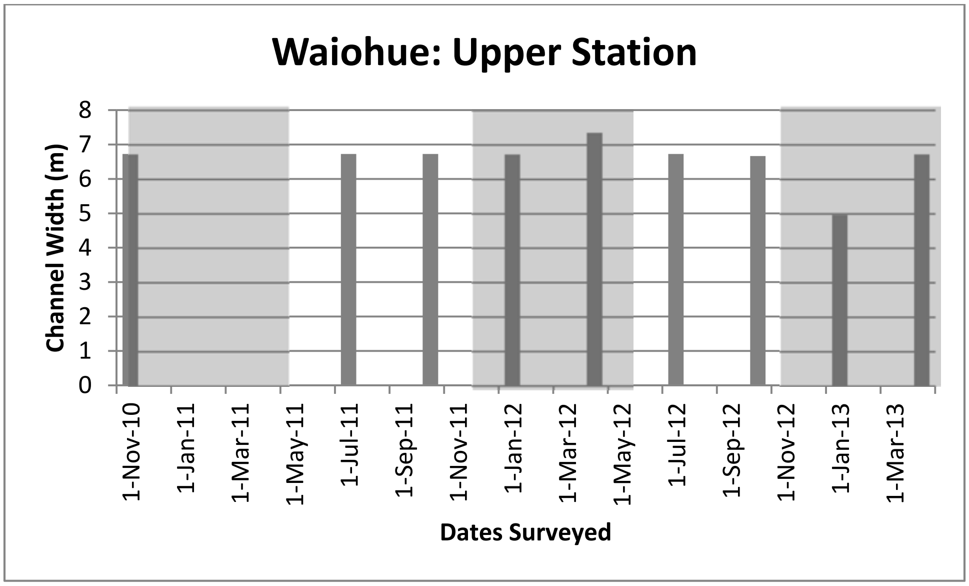


Figure 51. Average channel width in the Upper Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

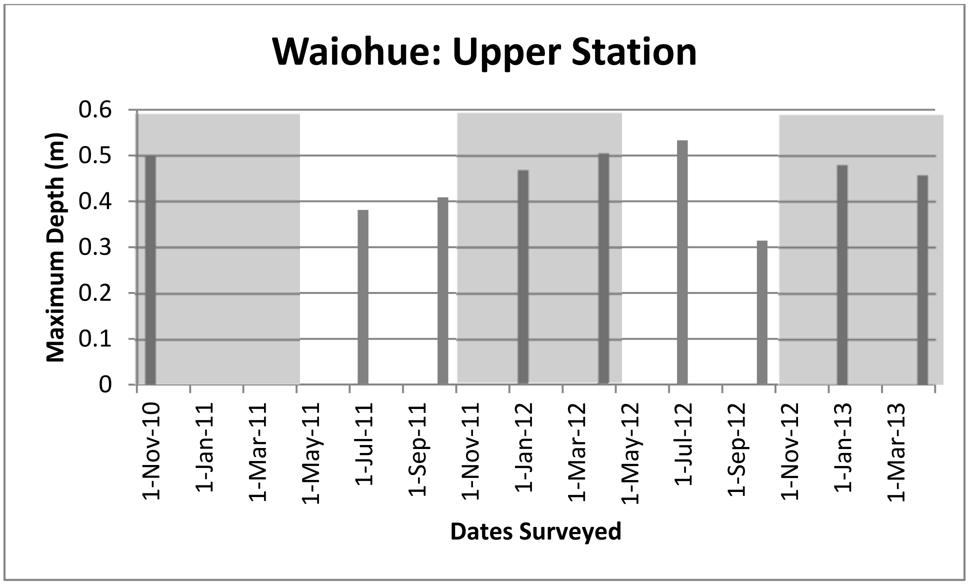


Figure 52. Average maximum stream depth in the Upper Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons

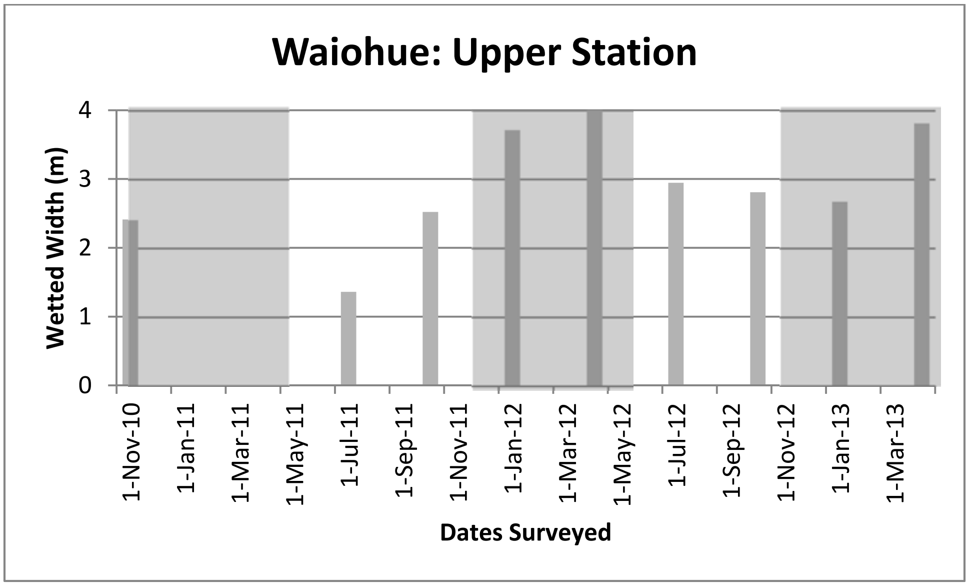


Figure 53. Average wetted width in the Upper Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

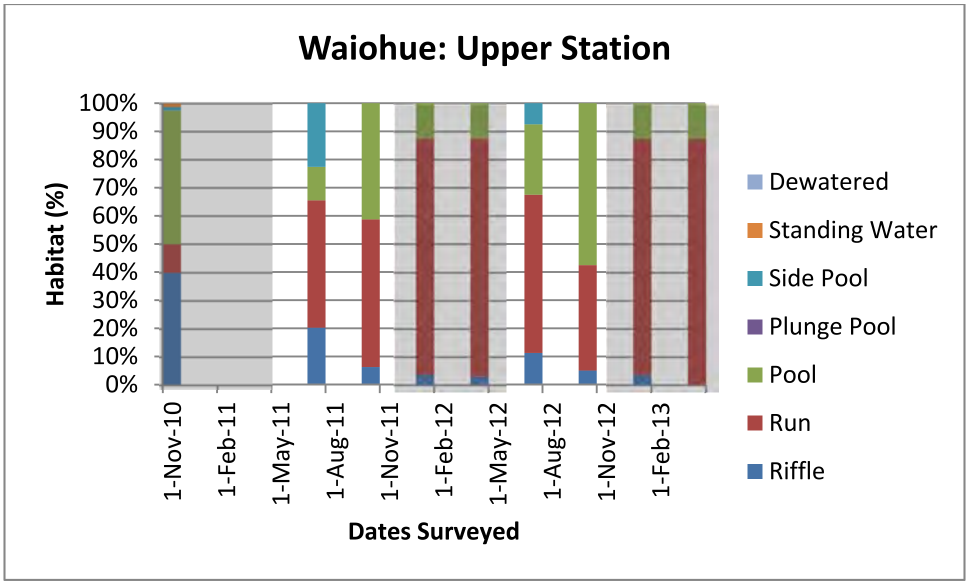


Figure 54. Habitat type by survey date for the Upper Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons

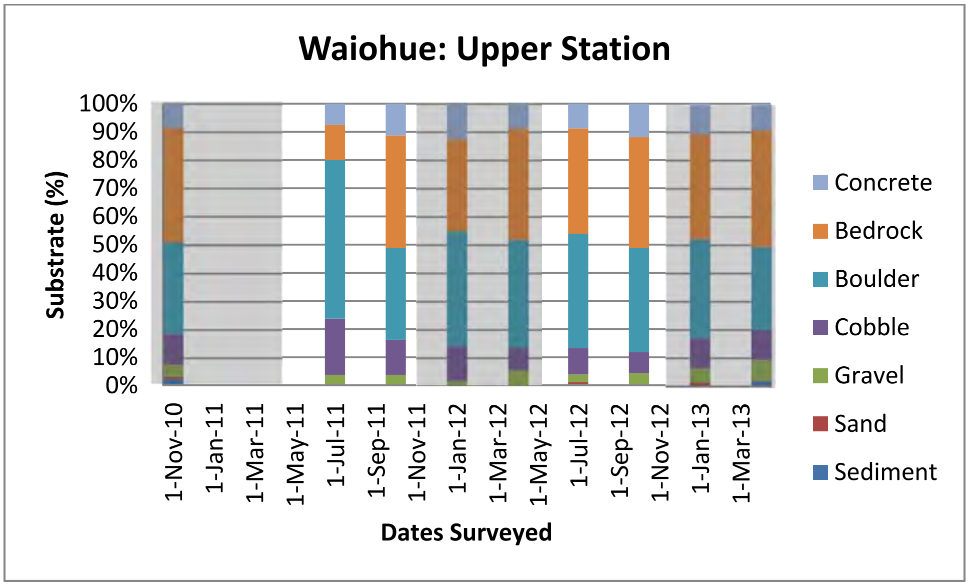


Figure 55. Substrate type by survey date for the Upper Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

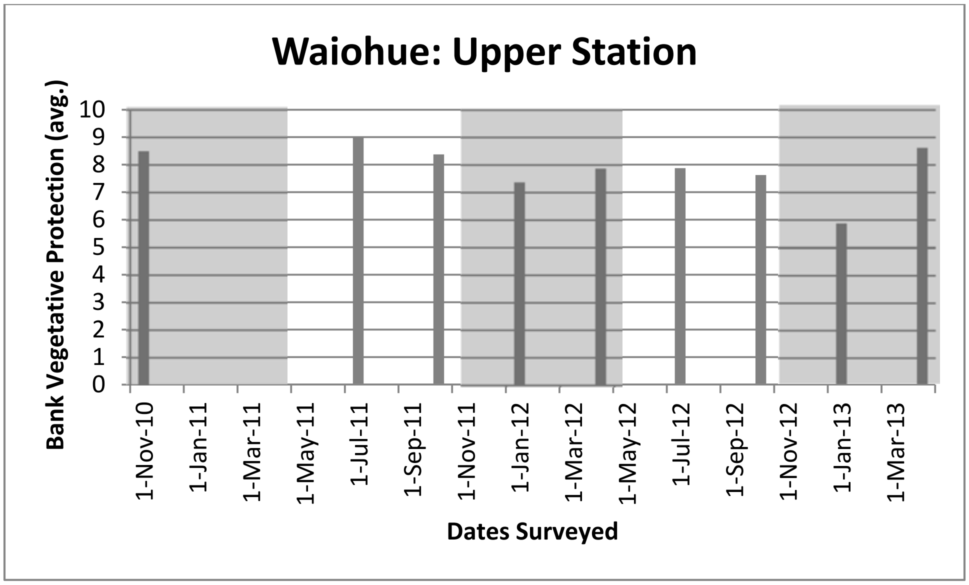


Figure 56. Average bank vegetation protection in the Upper Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

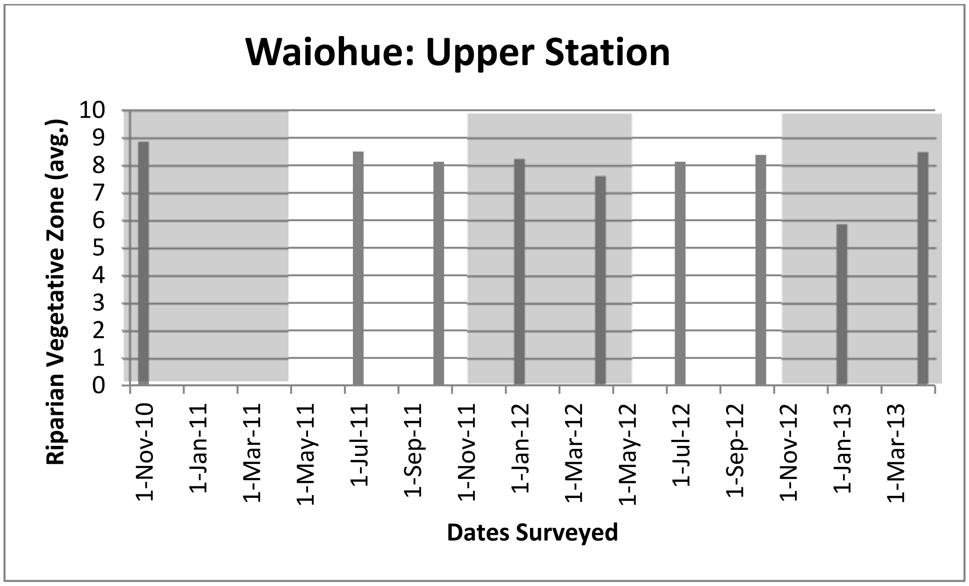


Figure 57. Average riparian vegetative zone in the Upper Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

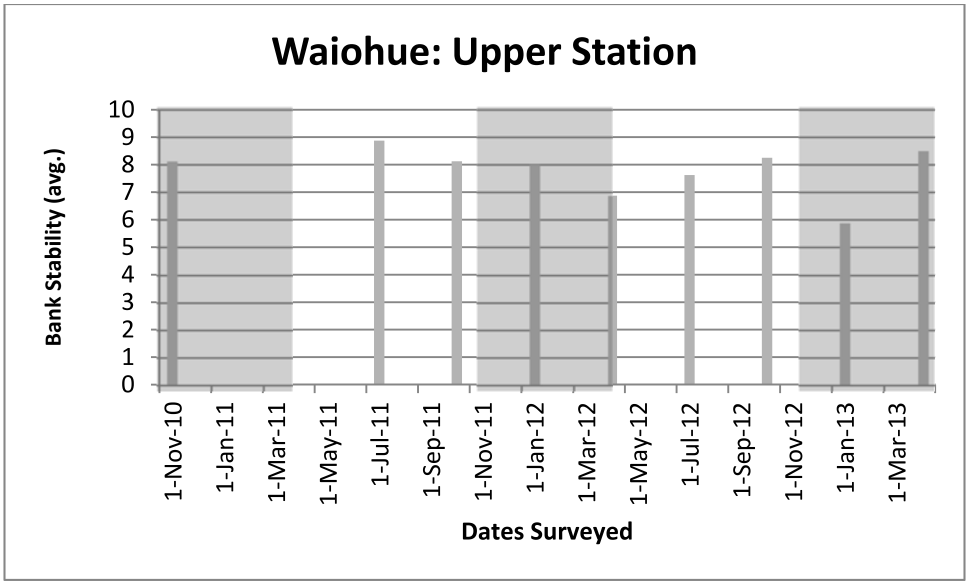


Figure 58. Average bank stability in the Upper Station of Waiohue. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

 1. Pre-water Release 11/30/10 Flow: 0.12 cfs	 2. Pre-water Release 7/14/11 Flow: 0.06 cfs
 3. Pre-water Release 10/13/11 Flow: -0.02 cfs	 4. Water Release 1/26/12 Flow: 2.07 cfs
 5. Water Release 4/12/12 Flow: 4.03 cfs	 6. Gate Closed 7/12/12 Flow: 0.21 cfs

7. Gate Closed 10/12/12 Flow: 0.53 cfs

8. Water Release 1/31/13 Flow: 1.67 cfs

9. Water Release 4/25/13 Flow: 2.11 cfs

Figure 59. Upper Station of Waiohue Site 3 upstream view during different survey dates and water releases.

Changes in Biota

East Wailua Iki: Lower Station

(Tables 2 to 10)

Lentipes concolor post-larvae were observed during one winter release period, but no conclusion can be made in relation to the water releases.

Sicyopterus stimpsoni appeared to have better recruitment during post-releases vs. pre-releases. The animals also appeared to be surviving and growing to at least medium size classes.

Awaous stamineus appeared to have better recruitment during post-releases vs. pre-releases, but the larger size classes were present in all surveys and appeared to be in similar numbers pre- and post-water releases.

Stenogobius hawaiiensis showed sporadic recruitment and growth at this station and did not show any clear pattern in relation to the water releases.

Eleotris sandwicensis was an abundant species at this station during all water release periods and the recruitment and size distribution were consistent over time.

Neritina granosa was an abundant species at this station and the recruitment appeared to be consistent in pre-releases vs post-releases. The large number of animals and size classes provide evidence of growth.

Neritina vespertina was an abundant species at this station as would be expected for its habitat. Their recruitment, size, and growth were consistent over time.

Atyoida bisulcata were occasionally present, but this was to be expected as their habitat and distribution is in the upper reaches. No conclusion can be made on the water releases.

Macrobrachium grandimanus was an abundant species at this station as would be expected for its habitat. Recruitment of this species appeared to be consistent for both post-releases vs. pre-releases. The numbers and size classes demonstrate that it is surviving and growing.

Overall, this appears to be a healthy station with the recruitment, growth, and range of species, but there appears to be no evidence that flow restoration (winter or summer) has had an impact. Note, this station’s stream mouth was closed to the ocean by the cobble berm during all survey dates and the pre- and post-releases did not appear to have an impact on the berm. However, the stream mouth was open to the ocean on one occasion as previously shown by the game camera photo in Figure 60. Also, rain storms and drought conditions may have had an impact on the recruitment at this site.

Table 2. *Lentipes concolor* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≤1	0	0	0	0	7	0	0	0	0
>1-≤2	0	0	0	0	0	0	0	0	0
>2-≤3	0	0	0	0	0	0	0	0	0
>3-≤4	0	0	0	0	0	0	0	0	0
>4-≤5	0	0	0	0	0	0	0	0	0
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 3 *Sicyopterus stimpsoni* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≤1	0	0	0	0	0	4	0	3	9
>1-≤2	0	8	7	22	16	39	19	11	18
>2-≤3	1	0	2	6	3	22	11	5	3
>3-≤4	0	0	0	1	1	8	7	1	2
>4-≤5	0	0	0	0	0	0	0	0	0
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 4. *Awaous stamineus* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≤1	0	0	0	0	6	7	1	0	3
>1-≤3	17	12	15	5	7	22	27	18	7
>3-≤5	14	9	6	8	8	7	8	4	2
>5-≤7	3	10	3	2	2	3	3	3	1
>7-≤9	2	1	2	5	1	0	1	0	3
>9	1	0	0	0	0	0	0	0	1

Winter water release

Summer water release

Winter water release

Table 5. *Stenogobius hawaiiensis* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≤1	0	0	0	0	0	0	0	0	3
>1-≤2	0	0	5	0	0	2	2	1	1
>2-≤3	2	3	0	1	0	0	1	0	0
>3-≤4	3	0	1	0	0	0	0	0	0
>4-≤5	0	0	0	0	0	0	0	0	0
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 6. *Eleotris sandwicensis* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≤1	0	19	0	0	0	0	0	0	2
>1-≤3	66	60	35	41	45	34	79	110	46
>3-≤5	21	23	34	15	22	21	35	55	33
>5-≤7	6	3	7	6	6	6	7	10	1
>7-≤9	2	1	1	2	1	1	0	3	1
>9	0	1	1	0	0	0	1	0	1

Winter water release

Summer water release

Winter water release

Table 7. *Neritina granosa* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≥0.25	0	0	0	0	0	0	0	0	0
>0.25-≤0.5	10	12	10	0	1	15	0	4	0
>0.5-≤0.75	30	42	54	7	6	37	11	9	16
>0.75-≤1.0	70	67	82	65	54	59	91	146	67
>1.0-≤1.5	138	57	91	92	104	109	172	215	61
<1.5	125	0	16	5	70	50	23	36	15

Winter water release

Summer water release

Winter water release

Table 8. *Neritina vespertina* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≥0.25	0	17	9	0	0	0	0	15	5
>0.25-≤0.5	3	0	31	40	48	21	17	80	15
>0.5-≤0.75	17	35	16	110	11	48	92	79	129
>0.75-≤1.0	14	0	18	45	17	122	134	112	80
>1.0-≤1.5	6	0	19	22	0	125	26	38	30
<1.5	0	0	0	0	0	13	0	0	0

Winter water release

Summer water release

Winter water release

Table 9. *Atyoida bisulcata* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≥0.25	0	0	0	0	0	0	0	0	0
>0.25-≤0.5	0	0	0	0	13	0	0	0	0
>0.5-≤0.75	0	0	0	0	0	0	32	0	0
>0.75-≤1.0	0	0	0	0	0	0	19	0	0
>1.0-≤1.5	0	0	0	0	0	0	0	0	0
<1.5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 10. *Macrobrachium grandimanus* numbers and sizes by survey dates for East Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≤1	0	0	0	3	6	35	0	1	12
>1-≤3	14	0	2	98	32	97	133	123	154
>3-≤5	3	0	0	24	26	37	66	35	41
>5-≤7	0	0	0	0	0	6	0	0	0
>7-≤9	0	0	0	0	0	0	0	0	0
>9	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

**Kuhlia xenura* and *Mugil cephalus* were also observed in the Lower Station, but were not included in the data tables.

East Wailua Iki: Upper Station

(Tables 11 to 13)

Lentipes concolor an adult pair was observed at the upper station during one survey post flow restoration. However, no other individuals were observed which appears to indicate that no new migration of post-larvae or juveniles has recently occurred.

Neritina granosa were observed in small numbers and large size classes. No conclusion can be made.

Atyoida bisulcata was a common species at this station as expected for its habitat and range distribution. The recruitment and size distribution was consistent over time. There appeared to be connectivity over time for this species to reach the upper station.

Overall, the lower station appeared to have recruitment, growth, and range of expected species, while the upper station had mostly *Atyoida bisulcata*. Some evidence of improved connectivity was observed for *Atyoida bisulcata*, but little recruitment was observed for *Lentipes concolor* or *Neritina granosa* post-water releases.

Table 11. *Lentipes concolor* numbers and sizes by survey dates for West Wailua Iki – Upper Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons

Species size (in.)	SURVEY DATES								
	12/2/2010	7/12/2011	10/11/2011	1/24/2012	4/13/2012	7/10/2012	10/10/2012	1/29/2013	4/23/2013
<u><</u>1	0	0	0	0	0	0	0	0	0
>1-<u><</u>2	0	0	0	0	0	0	0	0	0
>2-<u><</u>3	0	0	0	0	0	0	0	0	0
>3-<u><</u>4	0	0	1	0	0	0	2	0	0
>4-<u><</u>5	0	0	0	0	0	0	0	0	0
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 12. *Neritina granosa* numbers and sizes by survey dates for East Wailua Iki – Upper Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	12/2/2010	7/12/2011	10/11/2011	1/24/2012	4/13/2012	7/10/2012	10/10/2012	1/29/2013	4/23/2013
≥0.25	0	0	0	0	0	0	0	0	0
>0.25-≤0.5	0	0	0	0	0	0	0	0	0
>0.5-≤0.75	0	0	0	0	0	0	0	0	0
>0.75-≤1.0	0	0	0	0	0	0	0	3	0
>1.0-≤1.5	0	0	0	0	0	0	0	11	0
<1.5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 13. *Atyoida bisulcata* numbers and sizes by survey dates for East Wailua Iki – Upper Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	12/2/2010	7/12/2011	10/11/2011	1/24/2012	4/13/2012	7/10/2012	10/10/2012	1/29/2013	4/23/2013
≥0.25	0	0	0	0	0	20	0	0	0
>0.25-≤0.5	0	0	4	2	0	22	0	0	0
>0.5-≤0.75	2	2	5	9	0	20	12	1	2
>0.75-≤1.0	19	1	7	0	0	22	24	4	9
>1.0-≤1.5	7	0	0	3	1	23	11	14	3
<1.5	0	0	0	0	1	20	3	0	0

Winter water release

Summer water release

Winter water release

West Wailua Iki: Lower Station

(Tables 14 to 20)

Lentipes concolor post-larvae were observed during two winter release and one summer release periods.

Sicyopterus stimpsoni post-larvae were observed recruiting and growth was evident by the existence of some large size classes.

Awaous stamineus was abundant at this station and the recruitment and size distribution was consistent over time.

Eleotris sandwicensis was present at this station but in lower numbers as compared to lower East Wailua Iki.

Neritina granosa was abundant at this station and the recruitment and size class distribution were consistent over time.

Atyoida bisulcata post-larvae observations document recruitment in this lower station.

Macrobrachium grandimanus were present in low numbers.

Overall, this appears to be a healthy station with the recruitment, growth, and range of species, but there appeared to be no clear evidence that either winter or summer flow restoration has had an impact on the numbers or sizes of the different fish populations. Differing from the East Wailua Iki lower, this station's stream mouth was open to the ocean and there was continuous flow to the ocean.

Table 14. *Lentipes concolor* numbers and sizes by survey dates for West Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
<u><</u>1	0	0	0	0	0	5	0	1	2
>1-<u><</u>2	0	0	0	0	0	0	0	0	0
>2-<u><</u>3	0	0	0	0	0	0	0	0	0
>3-<u><</u>4	0	0	0	0	0	0	0	0	0
>4-<u><</u>5	0	0	0	0	0	0	0	0	0
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 15. *Sicyopterus stimpsoni* numbers and sizes by survey dates for West Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
<u><</u>1	0	0	0	0	0	2	0	0	2
>1-<u><</u>2	10	0	0	0	0	1	0	4	0
>2-<u><</u>3	3	0	1	0	0	0	3	1	1
>3-<u><</u>4	1	0	2	0	0	1	1	0	6
>4-<u><</u>5	0	0	0	0	0	1	3	1	1
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 16. *Awaous stamineus* numbers and sizes by survey dates for West Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
<u><</u>1	0	7	2	6	0	4	0	0	7
>1-<u><</u>3	23	6	17	7	0	22	30	21	7
>3-<u><</u>5	17	1	10	5	0	17	5	9	3
>5-<u><</u>7	5	1	2	2	0	2	2	6	2
>7-<u><</u>9	0	0	1	0	0	0	0	1	0
>9	0	0	0	00	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 17. *Eleotris sandwicensis* numbers and sizes by survey dates for West Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
<u><</u>1	0	0	0	0	0	0	0	0	0
>1-<u><</u>3	3	1	0	1	0	5	4	3	2
>3-<u><</u>5	4	0	0	0	0	2	0	2	1
>5-<u><</u>7	1	0	2	0	0	0	3	1	0
>7-<u><</u>9	0	0	0	0	0	0	1	0	0
>9	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 18. *Neritina granosa* numbers and sizes by survey dates for West Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≥0.25	23	700	376	84	126	550	22	28	20
>0.25-≤0.5	9	1	25	11	16	21	1	18	2
>0.5-≤0.75	53	13	32	16	28	42	17	36	34
>0.75-≤1.0	30	13	56	34	28	34	24	54	24
>1.0-≤1.5	24	27	26	19	14	32	12	14	34
<1.5	0	7	9	21	9	9	5	14	18

Winter water release

Summer water release

Winter water release

Table 19. *Atyoida bisulcata* numbers and sizes by survey dates for West Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≥0.25	0	0	0	3	0	0	0	0	0
>0.25-≤0.5	0	0	0	1	0	0	0	1	0
>0.5-≤0.75	0	0	0	0	0	0	0	1	0
>0.75-≤1.0	0	0	0	0	0	0	0	0	0
>1.0-≤1.5	0	0	0	0	0	0	0	0	0
<1.5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 20. *Macrobrachium grandimanus* numbers and sizes by survey dates for West Wailua Iki – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	10/19/2010	7/13/2011	10/12/2011	1/25/2012	4/11/2012	7/11/2012	10/11/2012	1/30/2013	4/24/2013
≤1	0	0	0	0	0	1	0	0	0
>1-≤3	0	0	0	1	0	15	1	2	0
>3-≤5	0	1	0	0	0	4	0	0	0
>5-≤7	0	0	0	0	0	2	0	0	0
>7-≤9	0	0	0	0	0	0	0	0	0
>9	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Kuhlia xenura and *Mugil cephalus* were also observed in the Lower Station, but were not included in the data tables.

West Wailua Iki: Upper Station

(Tables 21 to 22)

Lentipes concolor only one post-larvae was observed at this station and a few adults. No conclusion can be made about the water releases

Atyoida bisulcata was abundant at this station and the recruitment and size class distribution was consistent over time. There appeared to be connectivity over time for this species to reach the upper station, but opae require less water than gobies to migrate.

Overall, the lower station appears to have recruitment, growth, and range of expected species, while the upper station has mostly *Atyoida bisulcata*. There appeared to be consistent connectivity for *A. bisulcata,* but results for *Lentipes concolor* were inconclusive.

Table 21. *Lentipes concolor* numbers and sizes by survey dates for West Wailua Iki – Upper Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	12/2/2010	7/12/2011	10/11/2011	1/24/2012	4/12/2012	8/7/2012	10/10/2012	1/29/2013	4/23/2013
≤1	0	0	0	0	0	1	0	0	0
>1-≤2	0	0	0	0	0	0	0	0	0
>2-≤3	0	0	0	0	0	0	0	0	0
>3-≤4	0	0	2	0	0	0	0	0	0
>4-≤5	0	0	0	0	0	0	1	0	0
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 22. *Atyoida bisulcata* numbers and sizes by survey dates for West Wailua Iki – Upper Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons

Species size (in.)	SURVEY DATES								
	12/2/2010	7/12/2011	10/11/2011	1/24/2012	4/12/2012	8/7/2012	10/10/2012	1/29/2013	4/23/2013
≥0.25	0	0	10	0	0	0	0	0	0
>0.25-≤0.5	0	0	40	3	0	0	40	3	10
>0.5-≤0.75	0	3	3	5	10	30	55	3	15
>0.75-≤1.0	39	9	9	2	2	28	30	2	9
>1.0-≤1.5	0	0	0	0	0	0	0	0	0
<1.5	18	0	1	2	0	3	1	3	1

Winter water release

Summer water release

Winter water release

Waiohue Stream: Lower Station

(Tables 23 to 30)

Lentipes concolor post-larvae were present.

Sicyopterus stimpsoni was a common species with sporadic recruitment and growth evident at this station by the presence of post-larvae, juveniles, and adults.

Awaous stamineus was abundant at this station and the recruitment and size class distribution was consistent over time.

Stenogobius hawaiiensis was occasionally present in low numbers for their usual habitat range.

Eleotris sandwicensis was present in low numbers.

Neritina granosa was abundant at this station and the recruitment and size class distribution was consistent over time.

Neritina vespertina were present in low numbers.

Macrobrachium grandimanus were present in low numbers.

Overall, this station has good habitat for all species, particularly for hihiwai (*Neritina granosa)*. No clear pattern exists among the animals with respect to the flow restoration.

Table 23. *Lentipes concolor* numbers and sizes by survey dates for Waiohue – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES						
	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	4/25/2013
≤1	0	0	0	4	1	0	0
>1-≤2	0	0	0	0	0	0	0
>2-≤3	0	0	0	0	0	0	0
>3-≤4	0	0	0	0	0	0	0
>4-≤5	0	0	0	0	0	0	0
>5	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 24. *Sicyopterus stimpsoni* numbers and sizes by survey dates for Waiohue – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES					
	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	4/25/2013
≤1	0	0	4	8	0	0	0
>1-≤2	1	2	4	25	3	7	4
>2-≤3	2	2	1	13	8	2	4
>3-≤4	0	0	0	0	0	1	2
>4-≤5	0	0	0	0	0	0	0
>5	0	0	0	0	1	1	0

Winter water release

Summer water release

Winter water release

Table 25. *Awaous stamineus* numbers and sizes by survey dates for Waiohue – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES						
	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	4/25/2013
≤1	1	0	0	13	0	0	0
>1-≤3	7	10	5	28	7	5	3
>3-≤5	9	7	8	19	25	13	12
>5-≤7	0	3	1	2	5	7	2
>7-≤9	0	0	1	0	2	2	1
>9	0	0	0	0	1	0	0

Winter water release

Summer water release

Winter water release

Table 26. *Stenogobius hawaiiensis* numbers and sizes by survey dates for Waiohue – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons

Species size (in.)	SURVEY DATES						
	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	4/25/2013
≤1	0	0	0	7	0	0	0
>1-≤2	0	0	2	4	0	0	0
>2-≤3	0	0	0	1	0	0	0
>3-≤4	0	0	0	0	0	0	0
>4-≤5	0	0	0	0	0	0	0
>5	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 27. *Eleotris sandwicensis* numbers and sizes by survey dates for Waiohue – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES						
	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	4/25/2013
≤1	0	0	0	0	0	0	0
>1-≤3	0	1	1	5	8	0	0
>3-≤5	1	0	1	3	2	3	2
>5-≤7	3	0	0	1	2	0	0
>7-≤9	0	1	0	0	0	1	2
>9	0	1	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 28. *Neritina granosa* numbers and sizes by survey dates for Waiohue – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES						
	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	4/25/2013
≤.25	669	428	613	758	430	95	92
>.25-≤.5	318	604	142	33	26	21	4
>.5-≤.75	143	460	121	31	54	29	3
>.75-≤1	75	267	29	19	41	21	13
>1-≤1.5	114	69	24	31	28	10	6
>1.5	114	69	24	31	28	10	6

Winter water release

Summer water release

Winter water release

Table 29. *Neritina vespertina* numbers and sizes by survey dates for Waiohue – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES						
	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	4/25/2013
≤.25	0	0	0	0	3	0	0
>.25-≤.5	0	0	0	0	2	0	0
>.5-≤.75	0	0	0	0	1	0	5
>.75-≤1	0	0	0	0	0	0	5
>1-≤1.5	0	0	0	0	0	0	0
>1.5	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 30. *Macrobrachium grandimanus* numbers and sizes by survey dates for Waiohue – Lower Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES						
	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	4/25/2013
≤1	0	0	0	0	0	0	0
>1-≤3	0	0	0	8	1	0	1
>3-≤5	0	0	2	7	0	1	0
>5-≤7	0	0	0	0	0	0	0
>7-≤9	0	0	0	0	0	0	0
>9	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Kuhlia xenura were also observed in the Lower Station, but were not included in the data tables. *Atyoida bisulcata* were not observed for all dates.

Waiohue Stream: Upper Station

(Tables 31 to 33)

Lentipes concolor were present at this station. More fish were observed in the summer surveys after the first winter releases, but these animals were not observed in the subsequent winter surveys.

Sicyopterus stimpsoni only one adult was observed at this station prior to any water restoration.

Atyoida bisulcata were present in low numbers. There appears to be connectivity over time for this species to reach the upper station.

Overall, we observed little positive impact of flow restoration on the biota in terms of numbers or growth. There appeared to be some connectivity between lower and upper stations as *Lentipes concolor* were present over time, but not at consistently greater numbers post-water restoration. It is possible we were observing the some of the same individuals over time, but in general, summer flow amounts appear not to support the maintenance of fish populations through to the next winter flow period. Either the fish are moving to more suitable areas or are not surviving in the survey area. Either way, it appears summer flows are not sufficient to carry over the fish into the next winter flow period.

Note: during surveys above the diversion waterfall plunge pool large *Lentipes concolor* and *Atyoida bisulcata* were observed. This suggests some continuity among sites above and below the diversion.

Table 31. *Lentipes concolor* numbers and sizes by survey dates for Waiohue – Upper Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	11/30/2010	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	1/31/2013	4/25/2013
<u><</u>1	0	0	0	0	0	0	0	0	0
>1-<u><</u>2	0	0	0	0	0	0	0	0	0
>2-<u><</u>3	0	0	0	0	0	1	0	0	0
>3-<u><</u>4	0	0	2	2	1	2	0	0	0
>4-<u><</u>5	1	0	0	0	0	1	4	0	1
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 32. *Sicyopterus stimpsoni* numbers and sizes by survey dates for Waiohue – Upper Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	11/30/2010	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	1/31/2013	4/25/2013
≤1	0	0	0	0	0	0	0	0	0
>1-≤2	0	0	0	0	0	0	0	0	0
>2-≤3	0	0	0	0	0	0	0	0	0
>3-≤4	0	0	1	0	0	0	0	0	0
>4-≤5	0	0	0	0	0	0	0	0	0
>5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Table 33. *Atyoida bisulcata* numbers and sizes by survey dates for Waiohue – Upper Station. Gray-shaded boxes represent winter seasons (Nov 1 – April 30) and white-shaded boxes represent summer seasons (May 1 – Oct 31). Water release occurs in the second and third winter seasons.

Species size (in.)	SURVEY DATES								
	11/30/2010	7/14/2011	10/13/2011	1/26/2012	4/12/2012	7/12/2012	10/12/2012	1/31/2013	4/25/2013
≥0.25	0	0	0	0	0	0	0	0	0
>0.25-≤0.5	4	0	1	1	0	0	0	0	2
>0.5-≤0.75	0	0	0	0	0	0	0	0	2
>0.75-≤1.0	0	0	0	0	0	1	0	0	0
>1.0-≤1.5	0	0	0	0	0	0	0	0	0
<1.5	0	0	0	0	0	0	0	0	0

Winter water release

Summer water release

Winter water release

Changes in Connectivity

East Wailua Iki

For the lower station on East Wailua Iki all species are present showing connectivity to ocean despite the presence of a cobble berm at the stream mouth. Although the stream mouth was closed during all the survey dates, there were times when it was open to the ocean as shown in the image capture on a time-lapse fixed-mount game camera on 2/19/2012 (Figure 60). At the upper station for East Waliua Iki there appeared to be connectivity over time for *Atyoida bisulcata* and *Neritina granosa* to be able to reach the upper station. For *Lentipes concolor,* no conclusion can be made as there were no increases in numbers and no appearance of small class sizes.

Figure 60. Open stream mouth at the lower station of East Wailua Iki Stream.

West Wailua Iki

For the lower station of West Wailua Iki a range of species were present supporting the observations of continuous connectivity to ocean. The upper station of West Wailua Iki appeared to have connectivity over time for *Atyoida bisulcata*. There appeared to be intermittent connectivity for *Lentipes concolor*, but it was not consistently observed during winter releases.

Waiohue

For the Waiohue lower station, all species are present showing continuous connectivity to the ocean. At the Waiohue upper station there appears to be connectivity over time for *Atyoida bisulcata* to reach the upper site. Consistent connectivity for *Lentipes concolor* and *Sicyopterus stimpsoni* were not observed. We observed mostly large adults and did not see smaller individuals recruiting to this station. The presence of any individuals confirms some connectivity, yet it does not seem to be fully connected for the fish at current flow levels.

Conclusions:

When considering instream flow quantities to support stream animals, it is axiomatic that 100% flow restoration to natural undiverted flow would be best for native stream animals. While this is a possible outcome, it is not generally the goal when setting instream flow standards. From DAR’s perspective, the management goal for the 27 East Maui streams was to find the minimum amount of water that supported healthy stream animal populations while providing maximum water available for other uses. With this as a target, DAR recommended a seasonal instream flow standard that attempted to maximize water availability while still preserving important characteristics of instream habitat conditions to support stream animal long-term population viability. To examine the results of the specific Interim Instream Flow Standard (IIFS) applied in East Maui Streams, DAR devised a monitoring study to assess the impacts of the IIFS flow restoration on native species’ habitat, population structure, and connectivity. The study results were not definitive, but suggest some general conclusions.

Changes to instream habitat

Some changes to instream habitat at the upper survey stations were observed in response to the higher wintertime flow releases. In general, dry, disconnected or slow water habitats were replaced by more connected swift-water habitats. These improvements to instream habitat reflected a change to a more stream-like environment. Based on our knowledge of stream animals found in mid to upper stream reaches, these changes should result in more suitable instream habitat. In contrast to the improvements observed at upper stations during the wintertime flow releases, the lower summer flows showed little to no habitat improvement. At all upstream stations under both flow regimes, no changes were observed to the stream bank conditions as the stream bank conditions were consistently good over time.

Although we did observe some positive changes during the winter releases, the correlation between return flows and habitat improvements was weak. The weak response in many measured variables may be an effect of the presence or absence of rainfall events prior to the surveys. The naturally variable flow conditions observed may have obscured some of the changes related to the flow restoration. CWRM did attempt to monitor rainfall with a rain gage in the area, but the rain gage failed during the study period and thus was not useful for comparison with the study results.

At the lower monitoring stations, little change was observed to instream habitat with respect to either winter or summer flow releases. This was not an unexpected result. The lower stations were just upstream from the stream mouth and had perennial flow prior to the flow restorations. East Wailua Iki was impounded by a cobble berm and the large pool was tidally influenced thus further obscuring the direct effects of streamflow restoration. The most change, although inconsistent, was observed on Waiohue Stream. This was the narrowest stream and the increased stream flow appeared to improve instream habitat during the winter flow releases.

Changes to stream animal population

In the lower stations of all streams, the stream animal assemblages appear healthy and diverse with good recruitment from the ocean and display composition structure typical of Hawaiian streams. A range of size classes for most stream animals were observed in the lower stations and this pattern likely reflects that suitable conditions existed for feeding, growth, courtship and reproduction. However, over time the small size classes seemed to disappear rather than increase the total number of individuals in the lower station. This may reflect continued movement to sites upstream of the survey area, that the station was near its carrying capacity, or possibly some undetected problem was occurring with the animals themselves.

Macrobrachium grandimanus was observed in the lower stations of all three streams in different size classes and with berried females supporting growth and reproduction. *Neritina granosa* and *Neritina vespertina* were also observed in the lower stations in all three streams in different size class groups and with egg capsules present supporting the biological functions of recruitment, growth, and reproduction. The estuarine and low reach species of *Kuhlia xenura* and *Mugil cephalus* were also regularly observed in different size classes supporting recruitment and growth in the lower stations of all three streams. While no reproduction was directly observed for the gobies, *Awaous stamineus*, *Sicyopterus stimpsoni*, *Stenogobious hawaiiensis*, and the sleeper, *Eleotris sandwicensis* were consistently observed in multiple size classes supporting the contention that lower reach conditions were suitable to recruitment and growth of these species.

In the upper stations of all streams, stream animal assemblages did not show the healthy characteristics observed in the lower stations. In general, we did not see consistent patterns of occurrence, growth in numbers, or increases in size classes of the animals. As expected based on its habitat and range distribution, *Atyoida bisulcata* was the most common species and some recruitment and growth were observed in East and West Wailua Iki streams. While conditions may have been suitable for *A. bisulcata*, few *Lentipes concolor*, *Sicyopterus stimpsoni*, and *Neritina granosa* were observed in the upper stations suggesting poor quality habitat for these species over time. These species were observed sporadically suggesting that long term growth and survival at these upper stations was poor and that the seasonal flow releases were not suitable for stable populations. It is possible that some animals were missed between surveys, contributing to the inconsistent observations, but surveyors also noted that animals were not observed outside of the survey locations in typical habitats suggesting that the animals were rare in the upper stations.

While the photos of the upper stations during the winter and summer flow releases show that there is an impact on instream habitat conditions as a result of the winter flow releases, the response of the biota to the habitat improvement was not evident. The non-response to the winter flow releases could be a result of various factors such as a slow biotic response to the habitat changes, migration of animals further upstream to more suitable sites, or that the summer flows were too low and removed gains from the winter releases. Overall, the flow releases did not result in obvious improvements to the biota at the upper stations.

Changes to Connectivity

Connectivity for amphidromous animals is important in two ways. First, the animals need to migrate upstream to suitable habitats from the ocean after their marine larval phase. Second, the newly hatched larvae need to drift downstream from the instream hatching locations to the ocean to successfully condition their larval development. In this study, only indicators of upstream connectivity were considered as it would have been too time-consuming and costly to effectively measure downstream larval drift.

To observe improvements in connectivity as a result of flow restoration, we would expect to see increased numbers of small individuals appearing in the upper stations over time. Under the seasonal flow concept, both winter and summer flows should have supported connectivity flows. In general, we only observed consistent recruitment of small individuals for *Atyoida bisulcata* to the upper stations over time to support that adequate connectivity flows were present. While the upper sites showed some connectivity for *A. bisulcata*, we did not observe increases in recruitment numbers comparing post-release periods to pre-release periods for *Lentipes concolor, Sicyopterus stimpsoni*, or *Neritina granosa.* This suggests a differential ability to migrate during low flows among species or that overall recruitment of *A. bisulcata* was higher during the study period. Both of these possibilities may have been observed in our study. One interesting note was that *Marcobrachium lar*, an introduced amphidromous species, were observed in both upper and lower stations supporting its recruitment, connectivity, and growth, in the upper reaches.

It is important to remember that the upper stations were below the diversions and therefore passage and entrainment issues at the diversions were not addressed in this study. Passage and entrainment at water diversion sites is an important topic and will need to be addressed for more effective stream animal restoration to occur. It should also be noted that just below the Hana Highway for the East and West Wailua Iki Streams there is a tall waterfall which is also below the upper stations for these streams. As a result, passage is unlikely to be an issue at the upper diversion sites, but entrainment of animals should be minimized to all practical extent.

General thoughts

The seasonal flow hypothesis (higher winter flows and lower summer flows) was conceptually coherent, yet not supported by the data. It could be the prescribed flow amounts were insufficient (i.e. needed higher flows in summer) or that a year round minimum flow is more appropriate in East Maui streams.

The correlation between return flows, habitat, and biota was weak. This may be due to a number of factors including: changing environmental conditions (e.g. rainfall, drought, flash flooding), short monitoring period (>4 years), and/or that summer flows were detrimental to gains in habitat and biota from the winter flows. A longer monitoring period with more stations distributed more thoroughly throughout the stream may improve results, but this was not possible due to time and funding constraints. Inaccessibility also prevented the selection of more evenly distributed stations throughout the stream.

The results of this study are important for several reasons. First, this represents the first multi-stream attempt at monitoring changes over time to stream biota and habitat with respect to stream flow restoration. Second, the results of this work are intended to be used in an iterative process for setting an Interim Instream Flow Standard within an adaptive management framework. Finally, this study was a direct observation of the suitability of seasonal flows for use in IIFS for Hawaiian streams.

References:

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

Fitzsimons, J.M., J.E. Parham, and R.T. Nishimoto. 2002. Similarities in behavioral ecology among amphidromous and catadromous fishes on the oceanic islands of Hawai'i and Guam. Environmental Biology of Fishes. 65:123-129.

Gingerich, S.B. 2005. Median and Low Flow Characteristics for Stream under Natural and Diverted Conditions, Northeast Maui, Hawaii: Honolulu, HI. U.S. Geological Survey Scientific Investigations Report 2004-5262, 72 p.

Gingerich, S.B. and Wolff, R.H. 2005. Effects of surface-water diversions on habitat availability for native macrofauna, northeast Maui, Hawaii: U.S. Geological Survey Scientific Investigations Report 2005-5213, 93 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo‘o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on West Wailua Iki Stream, Maui, Hawai‘i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 57 p.

Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo‘o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on East Wailua Iki Stream, Maui, Hawai‘i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 52 p.

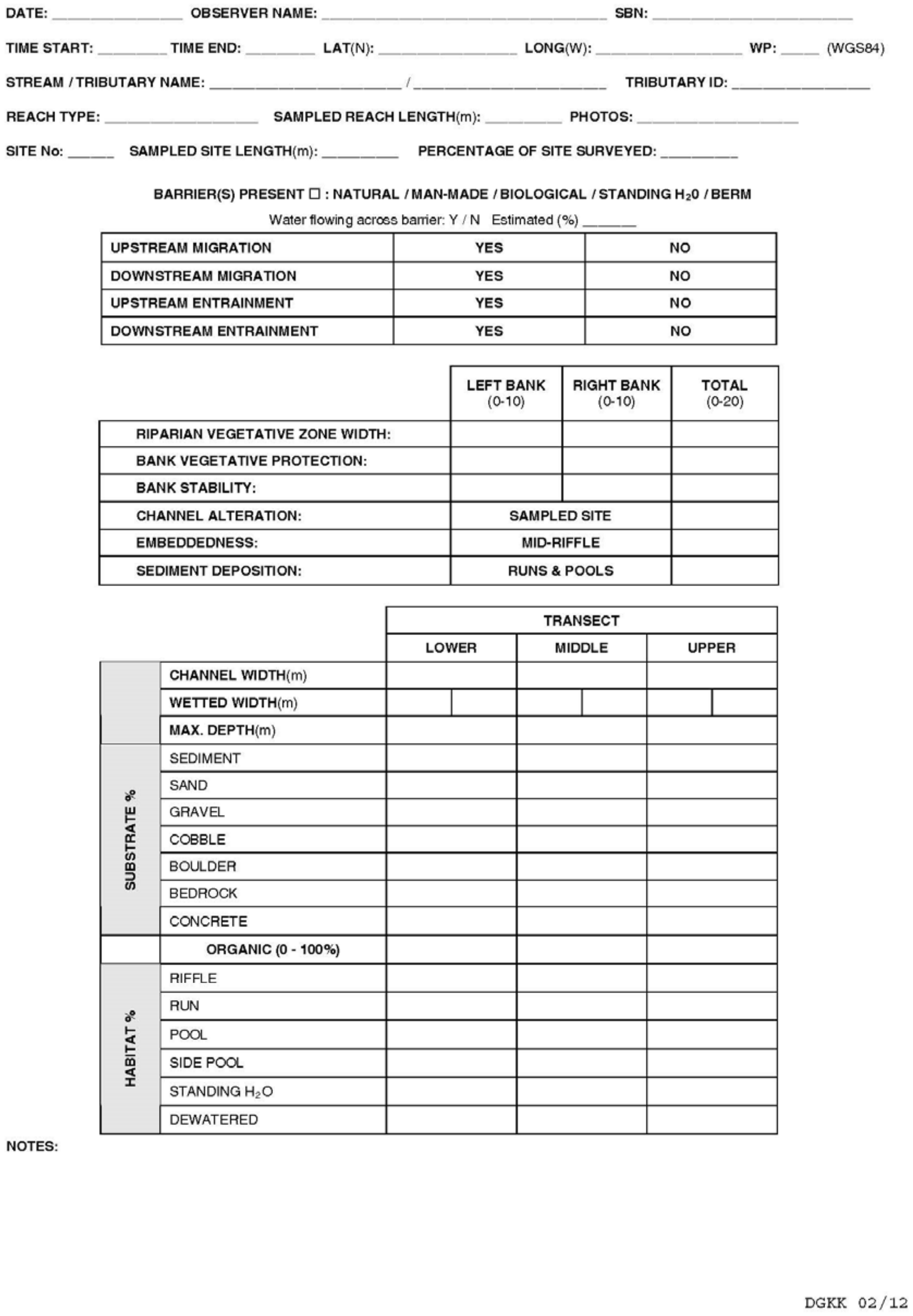
Higashi, Glenn; James Parham; Eko Lapp, Skippy Hau, Darrell Kuamo‘o, Lance Nishiura, Tim Shindo, Troy Sakihara, Troy Shimoda, Robert Nishimoto, and Dan Polhemus. 2009. Report on Waiohue Stream, Maui, Hawai‘i. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 60 p.

Parham, J. E., G. R. Higashi, E. K. Lapp, D. G. K. Kuamo’o, R. T. Nishimoto, S. Hau, J. M. Fitzsimons, D. A. Polhemus, and W. S. Devick. 2008. Atlas of Hawaiian Watersheds and Their Aquatic Resources. Island of Maui. Division of Aquatic Resources and Bishop Museum. Honolulu, HI. 866 p.

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

Stankey, G. H., Clark, R. N., and B.T. Bormann. 2005. Adaptive management of natural resources: theory, concepts, and management institutions. Gen. Tech. Rep. PNW-GTR-654. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 73 p

Appendix 1: Monitoring Field Sheets



DATE: ______________ **OBSERVER NAME:** ______________________________ **SBN:** ______________________

TIME START: ________ **TIME END:** ________ **LAT**(N): ______________ **LONG**(W): ________________ **WP:** _____ (WGS84)

STREAM / TRIBUTARY NAME: ____________________ / ____________________ **TRIBUTARY ID:** ______________

REACH TYPE: ________________ **SAMPLED REACH LENGTH**(m): ________ **PHOTOS:** ________________

SITE No: _____ **SAMPLED SITE LENGTH**(m): ________ **PERCENTAGE OF SITE SURVEYED:** ________

BARRIER(S) PRESENT ☐ : NATURAL / MAN-MADE / BIOLOGICAL / STANDING H$_2$0 / BERM

Water flowing across barrier: Y / N Estimated (%) ______

UPSTREAM MIGRATION	**YES**	**NO**
DOWNSTREAM MIGRATION	**YES**	**NO**
UPSTREAM ENTRAINMENT	**YES**	**NO**
DOWNSTREAM ENTRAINMENT	**YES**	**NO**

	LEFT BANK (0-10)	**RIGHT BANK** (0-10)	**TOTAL** (0-20)
RIPARIAN VEGETATIVE ZONE WIDTH:			
BANK VEGETATIVE PROTECTION:			
BANK STABILITY:			
CHANNEL ALTERATION:	**SAMPLED SITE**		
EMBEDDEDNESS:	**MID-RIFFLE**		
SEDIMENT DEPOSITION:	**RUNS & POOLS**		

		TRANSECT		
		LOWER	**MIDDLE**	**UPPER**
	CHANNEL WIDTH(m)			
	WETTED WIDTH(m)			
	MAX. DEPTH(m)			
SUBSTRATE %	SEDIMENT			
	SAND			
	GRAVEL			
	COBBLE			
	BOULDER			
	BEDROCK			
	CONCRETE			
	ORGANIC (0 - 100%)			
HABITAT %	RIFFLE			
	RUN			
	POOL			
	SIDE POOL			
	STANDING H$_2$O			
	DEWATERED			

NOTES:

DGKK 02/12

Species	≤1"	T	>1" and ≤2"	T	>2" and ≤3"	T	>3" and ≤4"	T	>4" and ≤5"	T	>5"	T
Unidentified												
S. hawaiiensis												
S. stimpsoni												
L. concolor												

Species	≤1"	T	>1" and ≤3"	T	>3" and ≤5"	T	>5" and ≤7"	T	>7" and ≤9"	T	>9"	T
A. guamensis												
E. sandwicensis												
M.grandimanus												

Species	≤1/4"	T	>1/4" and ≤1/2"	T	>1/2" and ≤3/4"	T	>3/4" and ≤1"	T	>1" and ≤1 1/2"	T	>1 1/2"	T
N. granosa egg capsules present ☐												
N. vespertina egg capsules present ☐												
A. bisulcata												

kuliidae sp.(972) S M L ___, *K. sandvicensis(973)* S M L ___, *K. xenura(006)* S M L ___, *mugilidae sp.(016)* S M L ___, *M. cephalus(007)* S M L ___
poeciliidae sp.(215) S M L ___, *P. reticulata(210)* S M L ___, *G. affinis(220)* S M L ___, *X. helleri(200)* S M L ___, *cichlidae sp.(215)* S M L ___
H. faciatus(229) S M L ___, *A. nigrofaciatum(230)* S M L ___, *O. mossambicus(270)* S M L ___, *O. macrochir macrochir(271)* S M L ___
S. melanotheron heudelotii(272) S M L ___, *T. zillii(274)* S M L ___, *cyprinidae sp.(283)* S M L ___, *C. carpio carpio(280)* S M L ___
C. idella(282) S M L ___, *C fuscus(310)* S M L ___, *assiminea sp(319)* S M L ___, *A. temminckii(320)* S M L ___, *H. watwata(325)* S M L ___,
L. multiradiatus(330) S M L ___, *macrobrachium sp.(012)* S M L ___, *M, lar(800)* S M L ___, *P. clarkii(802)* S M L ___, *melania sp.(512)* S M L ___
lymnaeid sp.(500) S M L ___, *pomacea sp.(502)* S M L ___, *physidae sp.(511)* S M L ___, *helisoma sp.(506)* S M L ___,
B. marinus(400) S M L ___, *ranidae sp.(409)* S M L ___, *R. rugosa(403)* S M L ___, *R. catesbiana(405)* S M L ___, *H. baileyi(989)* S M L ___

P=present (1 to 9), C=common (10 to 19), A=abundant (20+)

Appendix 2: West Wailua Iki Stream Images

WEST WAILUA IKI – LOWER

Site#2 downstream view (sh002m-053p-042413)

Site#2 upstream view (sh002m-048p-042413)

WEST WAILUA IKI – UPPER (above highway)

Site#2 downstream view (sh002m-756p-042313)

Site#2 upstream view (sh002m-749p-042313)

Waterfall and bridge way above Site#4 just below the diversion (gh001p-071312). Note second waterfall above the bridge (see next photo).

Waterfall above the diversion

Downstream view of bridge from the dam wall

Upstream view from bridge of dam wall (right) and diversion (left side)

Diversion view from bridge

Modification to the West Wailuaiki Stream diversion at the Ko’olau Ditch as per Mr. Garrett Hew (9/20/11)

EMI has completed the diversion modifications to the Waiohue, East Wailuaiki and West Wailuaiki stream diversions on the Koolau Ditch by installing pipes on the left side of the waterfall to drop water onto the top left corner of the diversion dam.

Appendix 3: East Wailua Iki Stream Images

EAST WAILUA IKI - Lower

Cobble berm at stream mouth

Upstream view from cobble berm


Site#2 downstream view (dk002m-004p-042413)


Site#2 upstream view (dk002m-003p-042413)

EAST WAILUA IKI – UPPER (above highway)

Site#2 downstream view (dk002m-004p-012913)

Site#2 upstream view (dk002m-003p-012913)

Upstream of Site#4 stream pool just below diversion

Downstream view of area just below diversion (previous photo)

Downstream view of bridge from diversion

Upstream view from bridge of the diversion (right) and dam wall (left)

View of diversion and cascading fall in the background

Modification to the East Wailuaiki Stream diversion at the Koʻolau Ditch as per Mr. Garrett Hew (9/20/11)

EMI has completed the diversion modifications to the Waiohue, East Wailuaiki and West Wailuaiki stream diversions on the Koolau Ditch by installing pipes to drop water onto the top of the diversion dam.

Note pipe on left side of cascade

Pipe transferring water on diversion wall

Appendix 4: Waiohue Stream Images

WAIOHUE Lower Station

Site#2 downstream view

Site#2 upstream view

Site#3 upstream view-end of site due to small waterfall

UPPER STATION - Above highway

Waiohue waterfall just below Site#1

Site#2 downstream view (gh006m-015p-041212)

Site#2 upstream view (gh002m-001p-101212)

Site#4 downstream view (dk008m-016p-041212)

Site#4 upstream view with water entering stream from left bank diversion ditch (dk008m-015p-041212)

Black pipe from waterfall (gh002d-015p-041012)

Diversion intake to left of waterfall

On top of diversion intake tunnel

Intake tunnel (gh002d-019p-041012)

Water from tunnel gh002d-024p-041012

Control gate water flowing into stream (gh002d-022p-041012)

Diversion ditch connected to intake and just above site#4. Ditch release door and channel to the left of Lance's feet.

Flume from control gate into stream (gh002d-021p-041012)

Water returned to stream (gh002d-030p-041012)

Modification to the Waiohue Stream diversion at the Ko'olau Ditch as per Mr. Garrett Hew (9/20/11)

EMI has completed the diversion modifications to the Waiohue, East Wailuaiki and West Wailuaiki stream diversions on the Koolau Ditch by installing pipes from above the waterfall to drop water onto the top of the diversion dam.

Waterfall diversion pool above Site#4 note black pipe to left of waterfall (gh002d-018p-041012)

Pipe from waterfall (gh002d-015p-041012)

Dam wall in plunge pool downstream view

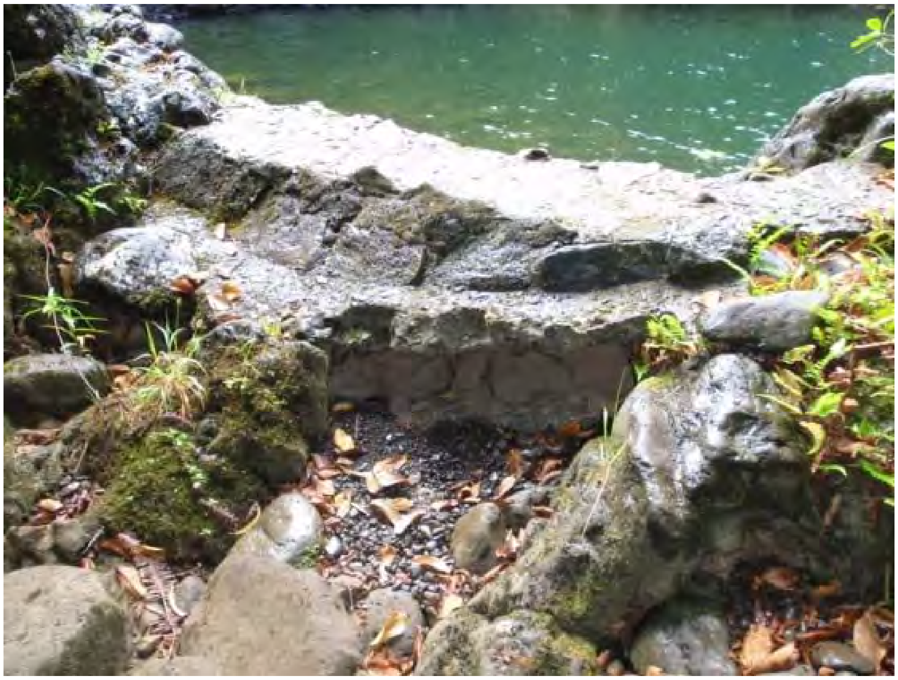
Pipe to dam (gh002d-017p-041012)

Dam wall with stream channel left and waterfall plunge pool right (gh002d-009p-041012)

Water flowing over dam wall (gh002d-011p-041012)

Not effective in providing connectivity at low flow

Waiohue waterfall plunge pool



Civil No. 19-1-0019-01 (JPC)

Defendant A&B/EMI's Exhibit AB-111

FOR IDENTIFICATION ___________________

RECEIVED IN EVIDENCE _________________

CLERK _________________________________