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Long-term ecological research and field methods for stream use decisions among oceanic islands of the tropical Pacific

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Abstract— Long-term ecological research (LTER) is essential for management, restoration, and conservation of tropical island streams, and it is the foundation for five components identified as crucial to wise stream use decisions. Survey methods derived from the Pacific-Asia Biodiversity Transect network (PABITRA) provide standardized procedures ensuring accuracy, uniformity, and completeness of comparative data on streams and aquatic animals. In the Hawaiian Islands, field data are permanently stored in a database maintained by the Hawai'i Division of Aquatic Resources (DAR). A formal classification of Hawaiian streams permits biological comparisons among streams similar in geomorphology. The Reference Condition Approach (RCA) determines conformity or deviation of a stream or site within a stream from certified reference conditions. The Instream Flow Council's (IFC) purpose, goals, and philosophy provide a framework for deliberations regarding stream protection and instream flow programs. An Action Plan developed from LTER and PABITRA used in combination with the DAR Database, Stream Classification, RCA, and IFC components is more likely to be scientifically sound, justifiable, and acceptable at any spatial scale, ranging from a single study site on a stream to an entire ecosystem. Although most research on island stream animals has been conducted in Hawai'i, the close evolutionary relationships of Hawaiian stream species with those on other high islands and the remarkable similarity in their ecology, behavior, and life cycles indicate that the discussions included herein are very likely relevant throughout the oceanic islands of the tropical Pacific.

Introduction

The intent of this paper is to introduce briefly an ordered series of procedures, techniques, and philosophies as an approach to wise stream-use decisions in island streams. The underlying incentive is readily apparent: In the conservation and management of island fresh waters, there is an overriding need for stream flow to support the native fauna. Although the work described has been completed mostly in Hawai‘i, our premise is that all of it in some fashion will be applicable to high islands throughout the tropics of the Pacific basin, where indigenous fishes and larger invertebrates in island streams are strongly allied by the evolutionary histories, by their amphidromous life cycles that include a marine stage, by their species-specific instream distributions, and by their striking similarities in behavior and ecology (Fitzsimons et al. 2002). This report is incomplete in that it does not provide step-by-step procedures for setting instream flow standards for individual streams. That capability lies in the near future, and, like the other methods described in this paper, it also will have its footing in long-term ecological research.

Whether the habitat under study is terrestrial, freshwater, estuarine, or marine, the importance of long-term ecological research (LTER) in management, conservation, and restoration can hardly be overstated. In Hawai‘i, LTER dating back to the 1960’s continues to provide a valuable and irreplaceable background for stream use decisions.

Indigenous fishes and macroinvertebrates in Hawaiian streams are strikingly different in their evolutionary origins, morphology, ecology, behavior, life cycles, and habitats in comparison to those species that typically occupy lotic environments on continents. Consequently, it is intuitive that survey and assessment methods developed for continental streams do not work well, if at all, for island stream ecosystems (Nishimoto & Fitzsimons 2007). When island data have been forced into an analysis developed for continental streams, the conclusions often were scientifically unsound and sometimes harmful (Fitzsimons et al. 2005). Fortunately, over a period of more than two decades, biologists with the Hawai‘i Department of Land and Natural Resources Division of Aquatic Resources (DAR) and their university colleagues have developed methods for unbiased surveys of Hawaiian stream animals at each stage of their life cycle and are compiling the information in an already comprehensive relational database. The purpose of this paper is to provide a framework of how objective stream methods and the DAR Aquatic Surveys Database can be used with other tools in a logical stepwise analysis to develop a rational biological foundation for stream-use decisions unarguably derived from the best available information from long-term ecological research. The details provided here are purposely simple and preliminary because they will be expanded and perfected through use in the same way that stream survey methods and the database for Hawaiian streams were developed.

This report does not presume to be the final word on “how to do it” regarding practical, far-sighted, and universally satisfactory stream-use decisions

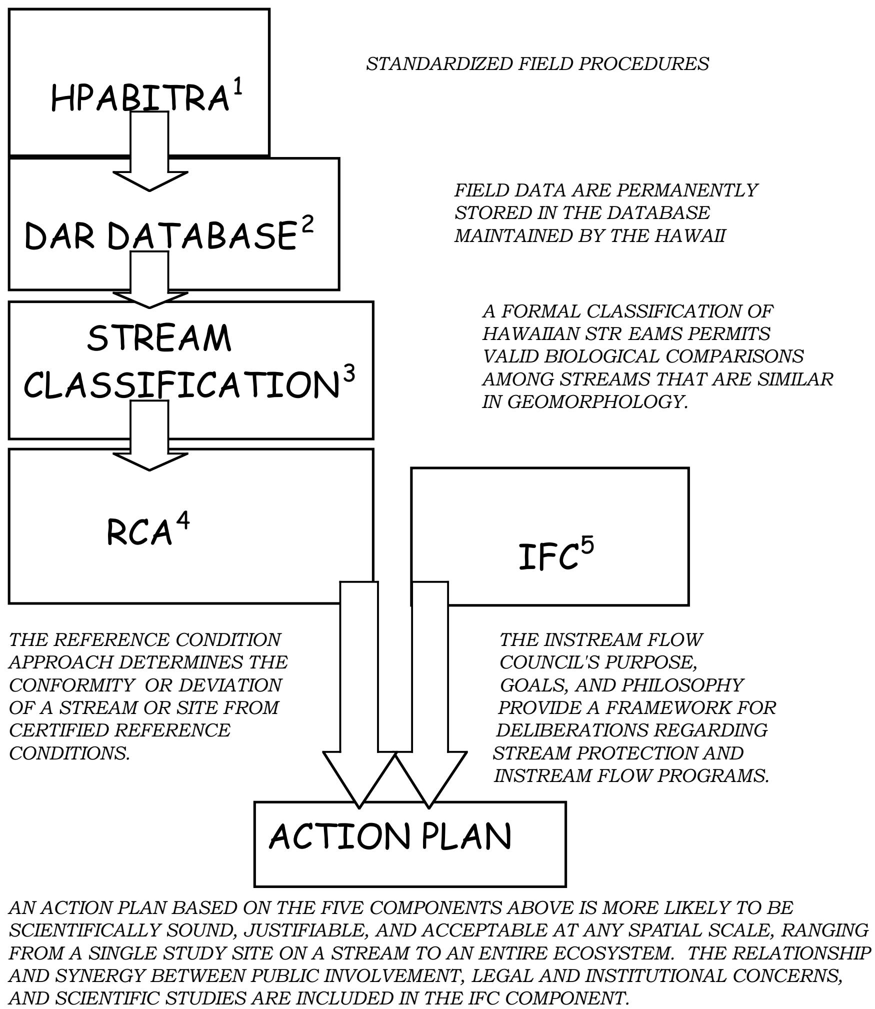

Figure 1. A basis for stream-use decisions in Hawai‘i. All components are rooted in long-term ecological research. [1]The “Hawaiianized” version of the stream survey section in the PABITRA Manual for Biodiversity Assessment of Tropical Islands Ecosystems (Mueller-Dombois et al. 2005, Fitzsimons et al. 2005, Fitzsimons in prep.); [2]Hawai‘i Freshwater Database, Division of Aquatic Resources (http://www.hawaii.gov/dlnr/dar/streams/stream_data.htm); [3]Classification of Hawaiian streams from basin morphology (Parham 2002); [4]Reference condition approach to stream assessment (Bailey et al. 2004); [5]Instream Flow Council principles of stream stewardship (Annear et al. 2004).

for the high islands of Hawai‘i and elsewhere in the Pacific. To begin with, the focus here is on the biological and physical attributes of a stream or group of streams. Social and economic considerations, minimally addressed in this paper, will most certainly be significant. In addition, the components (Figure 1) offered here as the basis for well founded stream-use decisions are themselves highly dynamic, and the interchange among them must remain fluid to be adaptive. In the following discussion, the sources of information indicated in Figure 1 are described briefly, and their association for use in Hawai‘i and on other islands is explored.

PACIFIC-ASIA BIODIVERSITY TRANSECT NETWORK METHODS FOR HAWAI‘I (HPABITRA)

The manuscript “Biological Surveys of Hawaiian Streams: Fishes and Larger Invertebrates” (Fitzsimons unpublished) is an adaptation for use in Hawai‘i of the stream survey procedures described in Chapter 7 “Stream Ecosystems” (Fitzsimons et al. 2005) as part of “Biodiversity Assessment of Tropical Island Ecosystems, the PABITRA Manual for Interactive Ecology and Management” (Mueller-Dombois et al. 2005). Chapter 7 and 11 others covering a broad range of topics related to biological surveys on oceanic islands are available as PDF files from the PABITRA website (www.botany.hawaii.edu/ pabitra/biodiversity/). PABITRA is an acronym for Pacific-Asia Biodiversity Transect Network, an organization developed by Dr. Dieter Mueller-Dombois and his colleagues at the University of Hawai‘i as an international collaborative program “for investigating the function of biodiversity and the health of ecosystems in the tropical Pacific Islands.” The acronym HPABITRA is used here as a convenient reference to Hawai‘i PABITRA.

DIVISION OF AQUATIC RESOURCES (DAR) DATABASE

The Division of Aquatic Resources Aquatic Surveys Database (http://www.hawaii.gov/dlnr/dar/streams/streamdata.htm) is the repository of information from many years of surveys and publications on Hawaiian stream animals, and it is of paramount importance “in monitoring, assessing, managing, and protecting the freshwater aquatic resources of the State of Hawai‘i” (quote from website). Hawai‘i has five freshwater lakes, numerous smaller impoundments, and 376 perennial streams, the latter located mostly on the windward coasts of the five main islands. The information contained in the database concerning these freshwater resources dates back to the 1960’s. The database encompasses the Hawai‘i Stream Assessment (1990), data from various survey types (Higashi & Nishimoto 2007, McRae 2007, Nishimoto & Kuamo‘o 1997), and information from numerous published and unpublished scientific reports. The Hawai‘i Stream Assessment was the first centralized base of stream-related data amassed during a cooperative project involving the Commission on Water Resource Management, Department of Land and Natural

Resources, the National Park Service Cooperative Park Studies Unit at the University of Hawai‘i, and the National Park Service Rivers, Trails, and Conservation Assistance Program. At the time of this writing, the database includes 339 watersheds with at least one biological survey and 7,419 point-quadrat surveys with 62,288 animal observations. Six hundred and forty-nine larval trapping sets included 12,663 animal observations. In addition to biological data for aquatic animals and physical descriptions of streams, the database includes other watershed information such as land cover, use, zoning, and ownership. Data for each stream provide its status as perennial or non-perennial and indicate the lengths of its estuary, low reach, middle reach, upper reach, and headwater sections.

The most recent iteration of DAR's relational database on Hawaiian streams and stream animals has evolved from its exhaustive redevelopment in 2001 to aid in the storage, retrieval, and analysis of information collected over time among all the islands (Kuamo‘o et al. 2007). The redesigned database has been upgraded to facilitate faster data entry, management, and analysis and to permit internet access by the public. An important feature of the database is the capability of integrating data into a Geographic Information System (GIS). Use of the database and its GIS capability is enhanced by a spatially nested hierarchical structure that ranges from the largest spatial extent being the entire island chain, through progressively smaller spatial extents (individual islands, regional units within an island, watersheds and their streams within a regional unit, stream segments within a stream, survey locations within a stream segment), down to individual observations within a survey location. This organization makes it possible to incorporate different survey designs within a single database and allows the assimilation of data from many kinds of research projects. Although the database will always continue to grow, it has long since contained sufficient information that it cannot be regarded as a mere compilation of random facts and figures relating to Hawaiian streams and their biota. Furthermore, the capability for retrieving information in response to a variety of questions (queries), limited perhaps only by the imagination of the inquirer, has elevated the DAR Database to the status of being an irreplaceable tool for research in its own right. Selected features of the database emphasizing watersheds and their resources are being printed in five volumes, one for each of the five major Hawaiian Islands (Parham et al. in press).

STREAM CLASSIFICATION

Native stream animals are not randomly distributed among islands, among streams on one island, or even within an individual stream (Fitzsimons et al. 2005). All individuals of all species enter streams at their mouths or estuaries as larvae moving from the ocean into fresh water, and the young animals continue upstream until they reach species-specific adult habitats where they mature, spawn, and complete their amphidromous life cycle. Stream morphology determines which species are capable of recruiting into a stream and which species are blocked from entry into the stream mouth or prevented access to upstream habitats. Valid comparisons of fauna among streams absolutely depend on these streams having similar profiles and similar basin configurations. Attempts to compare the "biological values" of dissimilar streams are patently misleading (Fitzsimons et al. 2005). A classification that allows Hawaiian streams to be grouped appropriately is of paramount importance.

Parham (2002) developed a series of spatially based models of Hawaiian streams and stream fish habitats for use in the conservation and management of indigenous fishes. The models identify and quantify habitats for stream fishes at three levels - reach, stream, and island - within a spatial hierarchy.

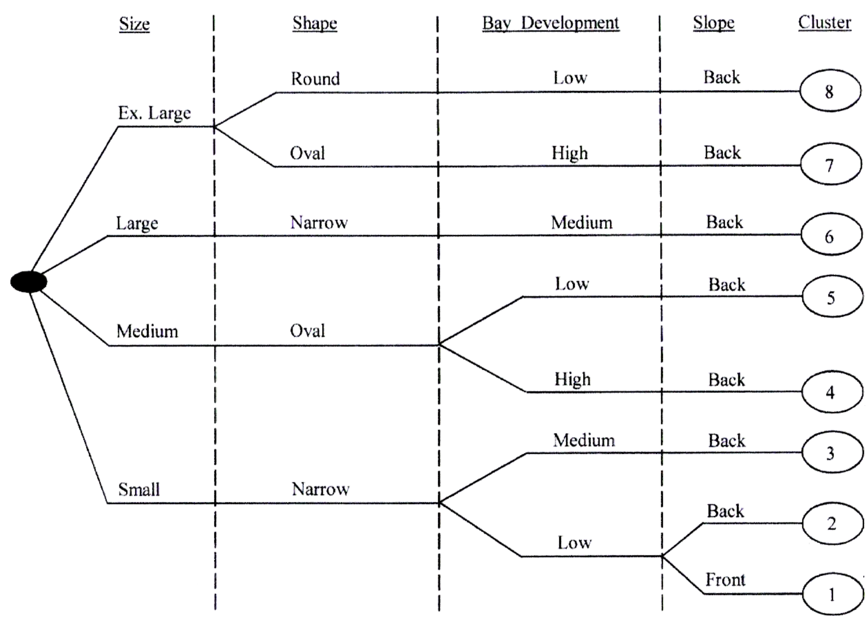

Figure 2. Diagrammatic key to the classification of Hawaiian streams from significant morphological features, from Parham (2002).

At the stream level, Parham (2002) devised a classification system for Hawaiian streams on the basis of the streams' major morphological characteristics (Figure 2). From a quantitative analysis of 150 perennial streams on the five major islands, eight stream types were classified as natural groups according to their size, shape, position of the steepest slope, and extent of bay development. He found that the distribution of stream types changed consistently with the age of the islands and that the amount and distribution of native fish habitats occurred non-randomly among stream types. As a result, these relationships can be used to predict an expected natural distribution of stream fishes and stream fish habitats. These expected distributions, in turn, can be used to constrain comparisons to streams with similar morphologies and are useful also for identifying attainable natural goals for stream restoration projects in altered streams.

In Hawai‘i, assessing the biological status of a stream traditionally meant comparing it to a “pristine stream”, a designation which usually implies that the reference stream is likely remote, has clear water, strong flow, and, most importantly, a full complement of native species. This approach is subject to error. Regardless of their locations, unless the reference stream and test stream are assignable to the same rank in the classification of stream types, there is no way of knowing whether the absence of one or more indigenous species is simply attributable to the stream’s morphology or is induced by a stressor, whether manmade or natural. A full complement of native stream species does not necessarily indicate that a stream has a healthy, reproducing assemblage of aquatic animals. Because of their amphidromous life cycle, every native fish and larger invertebrate in a Hawaiian stream is a migrant from the ocean. The adults may or may not have begun life in that stream, and the immature animals may or may not be their progeny. The presence of adults and juveniles in a stream does not in itself provide evidence that one or more populations are contributing offspring that reach the ocean and then successfully migrate back into fresh water. Determining whether a stream is a biological source or sink depends on the balance of larval animals transported from the stream into the ocean (drift) versus larvae returning to fresh water from the ocean (recruitment). A stream whose contributions to the offshore pool of larvae equal or exceed those coming in is a source stream. If more animals and more species come into a stream than are returned to the sea, the stream is a sink. Innovative research by McRae (2007) found source-and-sink characteristics of streams to be consistent with their position in the morphological classification of streams; certain of the larger, more spectacular Hawaiian streams with all native species present are actually reproductive sinks for some aquatic species while much smaller streams with one or two species are sources of larvae for potentially repopulating that stream and others.

REFERENCE CONDITION APPROACH

Once a stream is identified on the basis of its morphology and correctly placed into the classificatory scheme, the next task is to determine a basis of comparison for the stream in question with other streams of its type. The designation of any single stream as the reference stream is at best provisional and short-lived because that reference stream is certain to change over time. In lieu of selecting a single reference stream, the DAR Database can be used to define a reference condition against which a stream is assessed by retrieving data from several high quality streams of the same morphological type from nearby, from the same island, another island, or statewide. The Reference Condition Approach (Bailey et al. 2004), one of the more recent methods for assessing the condition of lakes, rivers, and streams, provides an unbiased instrument for that purpose.

The Reference Condition Approach (RCA; Bailey et al. 2004) "is established by standardized sampling of both the biota and its environment at a number of reference sites. A variety of environmental variables is measured in conjunction with sampling the biota." These conditions for establishing the RCA for work in Hawaiian streams are already being met by standardized HPABITRA field data, DAR's ongoing program of stream surveys throughout the islands, and the Division's database that accumulates the information in a highly usable format. Comparative data describe the biological and physical features of the streams selected for establishing an RCA, and, for quantitative data, both the means and ranges of values are included (Figure 3). Average conditions are important in understanding species requirements, but, even if infrequent, extreme conditions indicated by ranges of values may be critical in determining which species can persevere.

Applying the Reference Condition Approach to Hawaiian streams is limited here primarily to indicating whether each of the biological and physical features (descriptors) of the stream in question (test stream) falls within or outside the reference condition range. In brief, RCA is beneficial in determining whether a test stream conforms to the reference condition range and, if not, it indicates precisely those features in which it is different. Depending on the nature of the

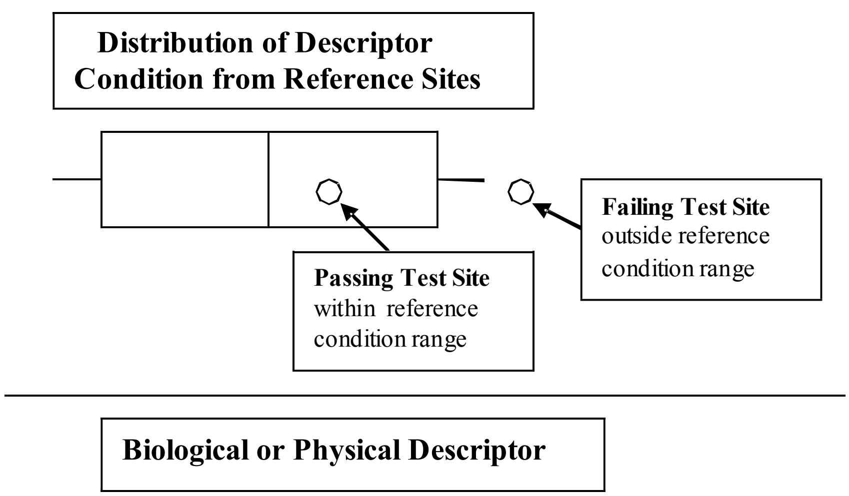

Figure 3. Comparing a feature (descriptor) of a site within a test stream to the reference condition derived from data describing conditions for several streams of the same morphological type as the test stream. (Adapted from Bailey et al. 2004).

stream-use question being addressed, a divergence from the reference condition may be of little significance or it may be of great importance for identifying specific problems that must be addressed, such as in restoration

INSTREAM FLOW COUNCIL

Prepared with objective data for the stream in question and comparable information from reference streams, the next step will be to consider the stream-use question in the context of responsibilities for conservation and management. The Instream Flow Council's "Instream Flows for Riverine Resource Stewardship" (Annear et al. 2004) provides a superior backdrop for assisting stream-use decisions in Hawai'i.

IFC has its origins in the National Instream Flow Project Assessment (NIFPA) begun in 1995 with a grant from the U.S. Fish and Wildlife Service (USFWS) to Christopher Estes and Keith Bayha to develop a procedure for evaluating state instream flow programs and those in use by USFWS. As a result of their work indicating a strong need to standardize procedures and to establish a network of biologists and water managers in the United States and Canada, IFC was formalized at its first meeting in March 1998 as a non-profit organization "whose mission is to improve the effectiveness of instream flow programs for conserving aquatic resources" (Annear et al. 2004). The IFC Principles for Riverine Resource Stewardship (Annear et al. 2004) provide, among other items, guidelines for promoting stewardship responsibility, working within legal and institutional limits, maintaining or restoring natural ecosystem functioning, involving the public, and following procedures that ensure a scientifically sound basis for stream use.

Public Trust Doctrine is an inseparable part of IFC's approach to the stewardship of water resources. This stance is evident in the IFC Public Trust Policy Statement: "Laws, regulations, and/or policies affecting fishery and wildlife resources and the habitats upon which they depend should be based on the state or province's legal stewardship responsibilities to manage those resources for the benefit and enjoyment of present and future generations" (Annear et al. 2004). Hawai'i's commitment to conserve and protect natural resources is in concert with Public Trust Doctrine. The Hawai'i Constitution (art. X, §1) states: "For the benefit of present and future generations, the state and its political subdivisions shall conserve and protect Hawai'i's natural beauty and all natural resources including land, water, air, minerals, and energy sources, and shall promote the development and utilization of these resources in a manner consistent with their conservation and in furtherance of the self-sufficiency of the state. All public natural resources are held in trust by the state for the benefit of the people." If the government of Hawai'i is able to reconcile short-term interests of the people with the need to conserve natural resources now and in the future, the groundwork will be laid for establishing an integrated instream flow program consistent with Public Trust Doctrine (Devick 2007).

The relationship between Public Trust Doctrine, the State Water Code (adopted in 1987), and other laws and regulations affecting water-use decisions is explained succinctly and unambiguously in "Water and the Law in Hawai'i" (Miike 2004). Dr. Miike's book is a "must read" for anyone professionally concerned with the conservation, management, and use of aquatic resources in Hawai'i. Although the legal aspects of water use in Hawai'i are emphasized, his account summarizes the historical, cultural, and biological perspectives that are vital background for accomplishing informed decisions.

PROTOCOL FOR BIOLOGICALLY BASED STREAM-USE DECISIONS

The procedure proposed for decision making and developing a provisional action plan rests on assumptions regarding categories of stream-use decisions and alternatives for proceeding once a decision has been reached. Stream-use decisions will fall naturally into one of four categories: preservation, restoration, mitigation, or no management.

Preservation

Complete protection for a stream will require maintaining the conditions that prevent or minimize to a sufficient degree human influences that precipitate permanent change in the aquatic community. Research has documented that seemingly catastrophic changes in streams from naturally occurring events, such as massive flash floods and hurricanes, do not lead to permanent damage although recovery may require two or more years (Fitzsimons & Nishimoto 1995). A return to a natural pattern of flow is the key to recovery. In this alternative, DAR's policy of "no net loss of habitat" (Devick 2007) is the prime directive to ensure the safety and continuance of the islands' indigenous stream organisms.

Restoration

The full restoration of a severely altered stream probably never results in a return to the original condition. The appropriate and attainable goal is returning the stream to a natural condition where many or most of the indigenous organisms are able to survive and reproduce. The Reference Condition Approach would aid in determining the appropriate actions needed to reduce the negative stressors of the stream system.

Mitigation

The goal of mitigation is to limit the negative consequences of changes to the aquatic communities as a result of human use of the water. In this case, understanding gained from LTER combined with data from a wide range of surveys may provide insight into which ecosystem modifications are the most detrimental and will support management practices that reduce the effect of the modification.

No management

Here, human-induced change to the environment would proceed without regard to the maintenance of native stream communities. Unless an unavoidable situation requires a complete dewatering of a stream or permanently blocking its connection with the sea, there may be ways to minimize habitat loss.

In Hawai‘i, most conflicts over water result from issues over water quantity allocation. Typically, water is diverted from a stream for use in agriculture, although municipal and industrial use is on the rise. These water withdrawals can be for the use of water within the originating watershed (intrabasin transfer) or for use in areas outside the originating watershed (interbasin transfer). Both of these would be considered consumptive use of water, although the return of water to an intrabasin stream would normally make this use more benign in terms of overall changes to the stream ecosystem. For example, it is an open question whether diversion of water through an *‘auwai* for growing taro and its subsequent return to the stream is a consistent example of a benign non-consumptive use of water. The answer would depend on many things such as loss of water through greater evaporation in the wide, shallow *lo‘i*, a change in temperature from solar radiation, the potential for flushing silt, fertilizer, and insecticides into the stream, and the occupation of the slow-water habitats in the taro patch by non-native fishes that function as reservoirs for parasites and diseases known to be transmitted to native stream fishes (Font 2007). Clearly, deciding whether non-consumptive use of water is detrimental or harmless requires case-by-case evaluation.

When at all possible, water should be removed from a stream in a manner that will not eliminate required habitats for stream animals. The fishes, crustaceans, and mollusks that are native to island streams are mostly benthic (bottom-oriented), so it is possible to withdraw a measured amount of water before the drop in level affects the animals. Because of the flashy nature of island streams, establishing specific flow standards is difficult. However, models based on point-quadrat data can estimate the effect on habitat availability of removing (or adding) water to a section of stream, and direct measurements in the field of spawning-site depths for mid- to downstream species can be useful also. These techniques focus on the need for adult habitats and should include data taken during both high and low water periods. An additionally important procedure would be based on measurements of flow and depth during times when larval drift and recruitment are occurring. This measurement would focus on the flow conditions needed for connectivity between the stream and ocean. Protection of flow sustaining instream habitats and the flow enabling migration in the amphidromous species is critical to maintaining viable populations of stream animals. If either of the necessary components of the animals’ life cycle is not considered, the flow standard may not achieve intended goals.

MINIMUM FLOWS VS. OPTIMUM FLOWS IN ISLAND STREAMS

It is crucial to distinguish between minimum flows and optimum flows when formulating stream use decisions on islands. A minimum flow is intended to prevent a specific condition from happening. For island streams, two main issues for minimum flow would be maintenance of instream habitats for adults and a continuation of stream to ocean connectivity for migration. These minimum flow amounts would not need to be the same in quantity, duration, or frequency. A single minimum flow setting would likely be ineffective if it only concerned the protection of flows at a low level for either connectivity or habitat alone. Minimum flow maintains the connection of a stream with the sea – with the goal of meeting the stream animals' requirement for completing amphidromous life cycles. However, if the minimum flow does not adequately allow the migratory events to be completed, then the minimum flow does not support its goal. Connectivity alone does not indicate favorable conditions for stream animals. The problem of minimally meeting only one of the stream animals' needs can be seen in case studies from Hawaiian streams. Long before the highly publicized Wai'āhole Contested Case Hearing (August, 2000), the connectivity of Oahu's Wai'āhole Stream and Kāne'ohe Bay was being maintained, but there was insufficient flow for drift and recruitment of indigenous stream animals even though habitats for adults were available inland. Instead, the sluggish lower stream reaches were literally packed with introduced livebearing poeciliid fishes heavily infested with parasites (leeches, flatworms, and roundworms) capable of using native stream fishes as hosts (see Font 2007). On the same island, Kahana Stream probably has always had connectivity with the sea, but the present overgrowth of hau (*Hibiscus tiliaceus*) in the estuary and lower reaches has largely shut down the obligatory migration of native aquatic species between stream and ocean.

Optimum flows are the preferred goal for water use decisions. Optimum flows are, by definition, the ones most advantageous, most favorable, and the best possible for stream animals. Optimum flows allow more aspects of hydrology and the animals' life history to be assessed. For example, the role of high flows in sediment transport and habitat creation or increased flows that initiate spawning may not be a minimum flow issue. Optimum flow standards could include protection for these flows in the management plan flows. The optimum flow would be based more on the natural flow paradigm and less on the absolute minimum needed by an individual species for a particular need. The optimum flow could contain minimum flow standards to protect specific conditions, but also contain additional flow criteria to protect the role played by high flows in island stream ecosystems. In actuality, water use decisions in Hawai'i must, by law, be based on optimum flows. A mandate (August 2000) from the Hawai'i Supreme Court is clear on this point: The State is charged with the firm requirement to assure "the maintenance of optimum flow for native fishes" throughout the islands.

It is now possible to provide a biological basis for defining optimum stream flows in island streams. Establishing required flows for an individual stream will require combining the biological data drawn from its assemblage of aquatic animals with information on the physical characteristics of its basin as a basis for forming predictions, testing them, and confirming or rejecting their validity and usefulness. Many years of long-term ecological research has served as the penultimate step in developing this capability. Hopefully, implementation will be an effort of much shorter term.

Acknowledgements

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References

Annear, T. & 15 authors. 2004. Instream Flows for Riverine Resource Stewardship. Instream Flow Council, Cheyenne, WY 268 pp.

Bailey, R. C., R. H. Norris & T. B. Reynoldson. 2004. Bioassessment of Freshwater Ecosystems. Using the Reference Condition Approach. Kluwer Academic Publishers, Norwell, MA.

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

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

Fitzsimons, J. M. (In press). A Guide for Biological Surveys of Hawaiian Streams: Fishes and Larger Invertebrates, 53 pp.

Fitzsimons, J. M. & R.T. Nishimoto. 1995. Use of fish behavior in assessing the effects of Hurricane Iniki on the Hawaiian island of Kaua‘i. Environmental Biology of Fishes 43: 39-50.

Fitzsimons, J. M., R. T. Nishimoto & J. E. Parham. 2005. Stream ecosystems. Chapter 7, pp. 103-136 *In*, D. Mueller-Dombois et al., eds. Biodiversity Assessment of Tropical Islands Ecosystems. The PABITRA Manual. (www.botany.hawaii.edu/pabitra/)

Fitzsimons, J. M., J. E. Parham & 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.

Font, W. F. 2007. Parasites of Hawaiian stream fishes: sources and impacts. In: Biology of Hawaiian Streams and Estuaries, N. L. Evenhuis & J. M. Fitzsimons, eds. Bishop Museum Bulletin in Cultural and Environmental Studies 3: 157-170.

Higashi, G. R., & R. T. Nishimoto. 2007. The point quadrat method: a rapid assessment 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: 305-313.

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.

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

Miike, L. H. 2004. Water and the Law in Hawai‘i. University of Hawai‘i Press Honolulu, HI.

Mueller-Dombois, D., K.W. Bridges & C. Daehler. 2005. Biological assessments of tropical island ecosystems. PABITRA Manual for Interactive Ecology and Management. Published online at http://www.botany.hawaii.edu/pabitra/

Nishimoto, R. T. & J. M. Fitzsimons. 2007. Status of native Hawaiian stream fishes, a unique amphidromous biota. American Fisheries Society Symposium 53: 59-65.

Nishimoto, R. T. & D. G. K. Kuamo‘o. 1997. Recruitment of goby postlarvae into Hakalau Stream, Hawai‘i Island. Micronesica 30: 83-91.

Parham, J. E. 2002. Spatial Models of Hawaiian Streams and Stream Fish Habitats. Ph.D. Dissertation, Louisiana State University, Baton Rouge, LA 149 pp.

Parham, J. E., G. R. Higashi, E. K. Lapp, D. G. K. Kuamo‘o, R. T. Nishimoto, J. M. Fitzsimons, D. A. Polhemus & W. S. Devick. (In press). Atlas of Hawaiian Watersheds and Their Aquatic Resources. Five volumes to include the islands of Hawai‘i, Maui, Moloka‘i, O‘ahu, and Kaua‘i.

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