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Status of Native Hawaiian Stream Fishes, A Unique Amphidromous Biota

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ABSTRACT Native Hawaiian stream fishes are represented by only five species belonging to two families, Gobiidae ('o'opu nakea *Awaous guamensis*, 'o'opu 'alamo'o *Lentipes concolor*, 'o'opu nopili *Sicyopterus stimpsoni*, and 'o'opu naniha *Stenogobius hawaiiensis*) and Eleotridae ('o'opu 'akupa *Eleotris sandwicensis*). All species are found on each of the main Hawaiian Islands, and none is currently threatened or endangered. These animals are not true freshwater fishes, but rather share an amphidromous life cycle where adults live and reproduce in streams and larvae develop at sea. Techniques developed for sampling (electroshocking, seining) and assessment (e.g., index of biotic integrity, instream flow incremental methodology) in continental U.S. streams are inappropriate for Hawaiian streams. Thus, procedures were developed specifically for fishes in streams on oceanic islands of the tropical Pacific where amphidromy is the predominant life history mode. Geographical information systems-compatible data from ongoing statewide native stream fish surveys can soon be viewed on the Web site for the Hawai'i Division of Aquatic Resources (http://www.hawaii.gov/dlnr/dar). The 2000 Hawai'i Supreme Court decision on the Waiahole Water Dispute specifically provides for the maintenance of optimum flow for native stream fishes, and the Division of Aquatic Resources has adopted policies guiding instream water use decisions: (1) no net loss of habitat for native fishes, (2) use of a watershed or ahupua'a perspective, and (3) maintenance of an open corridor between the stream and the ocean to facilitate native species migrations. The preservation of indigenous Hawaiian stream fishes now has been elevated to the highest level of protection in the state.

Four species of gobies and one eleotrid comprise the indigenous stream fishes of the Hawaiian high islands. Gobies and eleotrids occur around the world in temperate and tropical waters (Nelson 1984), but the evolutionary, behavioral, and ecological affinities of Hawaiian stream fishes rests among relatives in the oceanic islands of the tropical Pacific to the south and west of the Hawaiian Islands rather than to the east among fishes in coastal streams of North and South America (Fitzsimons et al. 2002a). These animals do not conform to traditional definitions as primary or secondary freshwater fishes because their life cycles include a marine phase. In Hawai'i, adults of three upstream species are limited to freshwater. Two other species occur as adults in lower sections of streams, estuaries, and river mouths where conditions range from completely fresh to brackish with salinities occasionally approaching that of seawater. These five species, together with two species of mollusks, an endemic prawn, and a shrimp, exhibit amphidromy (McDowall 1992), a kind of diadromous life cycle in which there are two migrations between freshwater and the sea. Spawning occurs in freshwater where eggs hatch within 48 h, and free-living embryos (sensu Balon 1990) are swept downstream into the ocean. Although the ocean phase of the life cycle for these fishes may be as long as 6 months (Radtke et al. 1988), the animals usually return to freshwater as glass-clear

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larvae with forked caudal fins and little or no pigmentation on the head and body (Tate et al. 1992; Nishimoto and Kuamo'o 1997). The distinction between amphidromy and other types of diadromy (e.g., anadromy and catadromy) is that immature animals are involved in both migrations and reproduction does not immediately follow access to habitats occupied by adults. There is no evidence for homing to a natal site, but young fishes migrating inshore toward the mouths of streams almost invariably orient toward a source of decreased salinity in tests offering a choice of full-strength seawater versus freshwater or even dilute seawater (Smith and Smith 1998).

Hawaiian freshwater fishes mostly occur on the north and east slopes of islands where trade winds produce the orographic rainfall that maintains perennial streams (Armstrong 1983). Streams with a full complement of native fishes are typically clear and cold and have a strong flow all year long. In such streams, there is little accumulation of sediment, leaf litter, and other loose debris because of uninterrupted flow and powerful freshets caused by localized heavy rains in the mountains or by the passage of weather fronts that can occur any time of the year but are most frequent during the rainy months (October to April). Because of frequent flash floods, Hawaiian streams are better described as dynamic rather than stable; each stream characteristically remains in a constant state of recovery from the most recent freshet. Native fishes in these streams survive not in spite of episodic floods, but actually because of them (Fitzsimons et al. 1996). Flash floods remove organic debris and sediments from spawning sites and restrict underwater vegetation to those species of algae (diatoms and low-growing filamentous species) representing early stages of succession in an aquatic community. These plant species are essential food items for one species of fish that is an obligate herbivore (Fitzsimons et al. 2003) and are important also in the diets of at least two other species of fishes. Floods facilitate migrations of amphidromous native stream fishes and macroinvertebrates by opening up the stream where it flows into the sea. There is increasing evidence that flood waters entering the sea provide a biological signal important in timing onshore migration of larval fishes that live as adults in freshwater streams. Finally, freshets, especially during the onset of the rainy season, trigger an increase in reproductive behavior. Ecosystem functioning in Hawaiian streams is based on recurring flash floods that maintain the colonizing species of fishes, invertebrates, and algae also as the principal members of the final stage of biotic succession (Fitzsimons and Nishimoto 1995; Fitzsimons et al. 2003). Understanding this relationship is significant when fishery management and stream-use decisions seek to preserve natural biodiversity in island streams.

From this background, our report offers brief descriptions of Hawaiian stream fishes, assesses their threatened/endangered status, explains the need for survey and monitoring procedures developed specifically for island streams, and describes how ecological and behavioral data have been used to establish policies for water-use decisions in the Hawaiian Islands.

Methods and Materials

Sources for the information provided here are the Hawai'i Stream Assessment (HSA), the stream database maintained by the Hawai'i Division of Aquatic Resources (DAR), a manuscript in progress on the natural history of Hawaiian streams and stream animals, and references cited herein. The HSA was distributed in December 1990 by the Commission on Water Resource Management, Department of Land and Natural Resources, State of Hawai'i; the report included baseline information on the location, physical features, and species present in perennial streams throughout the high islands in the southeastern section of the archipelago. At that time, HSA was the principal document for assisting with stream protection and management decisions. More recently, the DAR database has incorporated data from HSA along with subsequent surveys into a coding system that provides an eight-digit code for the identification of individual watershed units; data from animal abundance, distribution, ecology, behavior, recruitment, hydrology, anthropology, and the existence of photos and video recordings from each survey site are linked with the four-digit system employing geographic information systems

(GIS) analysis as the umbrella for integrating information in response to broad or narrowly defined queries.

Results

Species description and distribution

In Hawai'i, gobies and eleotrids are referred to collectively as 'o'opu (Pukui et al. 1983). Marine species are 'o'opu kai, the latter word in reference to the sea. Freshwater species are 'o'opu wai (meaning river, stream, or freshwater). Binomials are used also for individual fish species. As with binomial scientific names (genus and specific epithet), the first Hawaiian name indicates relationship and the second is descriptive of the species.

'O'opu akupa *Eleotris sandwicensis* ("bigmouthed 'o'opu") are endemic eleotrids easily distinguished from stream gobies by a prognathous lower jaw and separated pelvic (ventral) fins. 'O'opu akupa occur in estuaries, lower sections of streams, and occasionally in tide pools and anchialine ponds. These fish usually occur no farther upstream than the first waterfall. They are sit-and-wait predators on fishes and invertebrates. Observations of eggs, courting pairs, and recruitment of larvae indicate that akupa likely reproduce throughout the year.

'O'opu naniha *Stenogobius hawaiiensis* ("the 'o'opu that avoids") are endemic gobies readily identified by the black "tear drop" that extends from the lower edge of the orbit down and backward across the cheek toward the bottom of the operculum. 'O'opu naniha occur on all high islands of the Hawaiian Chain and are often the most common gobies in seaside pools, freshwater and brackish ponds, along the margins of streams, and especially in lower sections of streams with sand and gravel bottoms. These fish have the fused pelvic fins that form a sucking disk in true gobies, but, in contrast to upstream species, the structure is elongate, poorly muscled, and not well adapted for hanging onto rocks in strong currents. As a result, 'o'opu naniha are naturally restricted to downstream areas below the first waterfall and the fish are usually not found in high-gradient mountain streams that lack slowly moving water near the stream mouth. They are omnivores on benthic organisms, and they occasionally swim up to intercept items drifting downstream. Most courtship and spawning have been observed during summer months.

The indigenous 'o'opu nakea *Awaous guamensis* ("light colored 'o'opu") are light tan to pale green with a dark chain-like stripe extending along the midside of the body and tail and ending in a prominent dark spot or blotch at the base of the caudal fin. 'O'opu nakea are the most common native freshwater fish in the windward streams of the five major islands. Individuals of the 'o'opu nakea may be found anywhere along the length of a stream from the mouth to several miles inland, but greater numbers of animals are typical of middle sections of streams. Adults often bury themselves particularly at night in loose sand and gravel. The 'o'opu nakea feed on filamentous algae, diatoms, and small stream animals such as fly larvae, mollusks, and oligochaetes mostly ingested with vegetation. The fish usually bite off large clumps of algae or take in a mouthful of sand or gravel from which algae and invertebrates are removed by comb-like gill rakers in the animal's "pharyngeal mill." Once cleaned, particles of sand and gravel are spit out or allowed to drop from under the lower edge of the gill cover. Although typically bottom feeders, 'o'opu nakea occasionally swim up from the bottom and ingest pieces of material being washed downstream. 'O'opu nakea spawn mostly in the lower sections of streams from August through December.

'O'opu nopili *Sicyopterus stimpsoni* ("the 'o'opu that clings") is unique among native stream fishes in Hawai'i by having three notches in the upper lip (one median and two lateral versus one or none in other species) and by being an obligate herbivore (diatoms and filamentous algae). The 'o'opu nopili occur on all islands and are most common in shallow, swift parts of a stream well inland from the mouth. Their range in a stream usually overlaps the upper extent of 'o'opu nakea and the lower extent of 'o'opu 'alamo'o *Lentipes concolor*, but there are many exceptions. Their presence in a stream is often indicated by conspicuous feeding patches on the upper surface of rocks and boulders where algae are scraped from the substrate with sweeping movements of the upper jaw armed with elongate

tricuspid teeth. The ‘o’opu nopili spawn all year long, but most reproductive activity occurs during summer months.

The endemic ‘o’opu alamo’o (“lizard-like ‘o’opu”) differ sharply from other stream fishes in Hawai’i by having a single median notch in the upper lip and by usually occurring farther inland and above higher waterfalls than any of the other stream fishes. Courting males with jet black on the head and body anterior to the posterior edge of the first dorsal-fin base and bright red-orange on the posterior part of the body and tail further distinguish this species from other stream fishes. ‘O’opu ‘alamo’o feed opportunistically on stream invertebrates. In many streams, the most common food items are larvae of extremely abundant chironomid flies that lay their eggs on dampened parts of rocks near the water line. The pattern of recruitment of larvae from the ocean and the behavior of adults indicate that fish of this species spawn year round.

When migrating young fishes leave the ocean and move upstream, two species (‘o’opu ‘akupa and ‘o’opu naniha) typically penetrate upstream no further than the first waterfall or cascade (Fitzsimons and Nishimoto 1991). Three species have well-developed sucking disks (fused pelvic fins) and are able to climb waterfalls as high as about 20 m (‘o’opu nakea), 30 m (‘o’opu nopili), and more than 300 m (‘o’opu ‘alamo’o). Streams that have a short estuary and gentle grade in the lower reaches are likely to have all five species. Ones with a very long estuary may not include ‘o’opu ‘alamo’o. Conversely, streams that end in a waterfall dropping directly on the beach from a height of 15 m or more are likely to include ‘o’opu ‘alamo’o and perhaps ‘o’opu nopili but probably not the other species.

Species Status

Early stream surveys often missed species, especially ‘o’opu ‘alamo’o (Timbol et al. 1980), because the effect of stream morphology on species presence and distribution was unknown. Until recently, ‘o’opu ‘alamo’o was thought to be extinct on the island of O’ahu (Higashi and Yamamoto 1993), but all species are now known (Devick et al. 1992) from windward streams on each of the major high islands (Kaua’i, O’ahu, Moloka’i, Maui, and Hawai’i). Over a decade ago, ‘o’opu ‘alamo’o was labeled as endangered, and ‘o’opu ‘akupa, ‘o’opu nakea, and ‘o’opu nopili were listed as species of special concern in a publication by the American Fisheries Society (AFS; Williams et al. 1989). Subsequent surveys by the Hawai’i Division of Aquatic Resources leading to the publication of the Hawai’i Stream Assessment (Hawaii Cooperative Park Service Unit 1990) and the establishment of a statewide stream database have shown that the five species are not rare even on the island of O’ahu where they are now recorded from seven streams (Devick et al. 1995; Fitzsimons et al. 2002b). Currently, none of the species is listed as endangered, threatened, or of special concern by AFS, the U.S. Fish and Wildlife Service (Threatened and Endangered Species System), or the Hawai’i Biological Survey (Bishop Museum). However, because each island has a wet and dry side, and dry-side development requires water, water will always be a coveted and limited resource in Hawai’i and stream animals will remain vulnerable.

Instream Flow Incremental Methodology, Index of Biotic Integrity, Reference Condition Approach, and Pacific-Asia Biodiversity Transect Network

Typical Hawaiian streams resemble high quality trout streams on the North American continent, but the analogy is difficult to extend beyond superficial similarities because of frequent flash floods and a marine life history stage for fishes and larger aquatic invertebrates (Fitzsimons and Nishimoto 1997). These distinctions have made it imperative to develop stream survey methods that are appropriate for Hawai’i. Techniques arguably effective in mainland streams either cannot be used in island streams or are sharply limited in their applicability. Three examples are mentioned here.

Traditional sampling methods employing electroshocking, seining, or installing set nets are difficult to use in boulder-strewn island streams subject to sudden flooding. Between floods, however, underwater visibility may be 10 m or more; therefore, visual sampling has become standard.

Instream flow incremental methodology (IFIM) was developed by the U.S. Fish and Wildlife Service to provide, among other things, standard techniques for recommending minimum flow requirements for individual streams on the North American mainland (Estes and Osborn 1986). Although certain measurements in IFIM procedures can be used in Hawai'i for physical characterizations of streams (depth, velocity, substrate, and cover), the continuous seesaw effect of changing water levels that occurs naturally in island streams makes IFIM mostly inapplicable for Hawai'i. Frequent flash floods of a magnitude that would be disastrous on a continent and the subsequent return to greatly reduced flows and clear water in as few as 2 or 3 d make the setting of a precise minimum flow requirement for a Hawaiian stream both arbitrary and unachievable.

Procedures for developing an index of biotic integrity (IBI) or similar measure include useful items for describing stream conditions at a discrete point in time (Karr 1981; Karr et al. 1986). However, assessing the health ("biotic integrity") of a Hawaiian stream during a single visit by scoring physical conditions and by using species richness and numbers of individuals of indigenous fishes (the usual approach) or macroinvertebrates is inappropriate. A stream with a full complement of animals can receive, for example, a score of 10 in respect to water clarity in the morning, a zero during an afternoon flood, and back to a 10 two or three days later. Although once used commonly by mainland fishery biologists, evaluating streams by simply scoring the major aquatic species as present or absent can be misleading because the occurrence and local density of Hawaiian species are strongly influenced by stream topography. Island streams differ significantly from continental streams in respect to population origins; every native fish and larger invertebrate (crustaceans, mollusks) in every Hawaiian stream is a migrant. Adult animals in a stream may or may not (the latter is more likely) have begun life in that stream, and the young animals in the same stream probably are not their offspring. Therefore, the number of age-classes and number of individuals per class cannot be used to estimate a particular stream's productivity. Because indigenous stream fishes and macroinvertebrates are benthic species, counts of animals for use in population estimates can also be deceptive. At low water, the number of individuals per unit volume of water or per area of stream bottom will appear higher than the same number of animals when water level is higher and the animals are dispersed. Thus, the ranking of Hawaiian streams according to their "biological value" from a subjective scoring of physical features, the number of species present, or the number of individuals per unit area or volume is deceptive. The mistake is compounded when the composite score for a stream is compared with a reference stream in Hawai'i as a basis for recommending maintenance, special protection, or development. A reference stream, regardless of its high score, inevitably will change. The recently proposed reference condition approach (RCA) uses naturally occurring variability among streams and stream animals minimally exposed to human stressors as a reference for assessing individual streams (Bailey et al. 2004). This approach is logical for Hawaiian streams.

After more than a decade of collaboration by personnel in the Hawai'i Division of Aquatic Resources and the Louisiana State University Museum of Natural Science, a procedure for stream surveys in Hawai'i and other islands of the tropical Pacific was designed specifically to accommodate the amphidromous life cycles of stream fishes and larger invertebrates and the frequent flash floods that characterize high-island streams (Fitzsimons et al. 2005). These techniques are included in chapter 7 of *Biodiversity Assessment of Tropical Island Ecosystems, Pacific-Asia Biodiversity Transect Network (PABITRA) Manual for Interactive Ecology and Management* (Fitzsimons et al. 2005). Pacific-Asia Biodiversity Transect Network is a "collaborative program for investigating the function of biodiversity and the health of ecosystems in the tropical Pacific Islands." A description of PABITRA, an outline of the manual, and chapter contents are available at the Web site http://www.botany.hawaii.edu/pabitra/. The primary purpose of freshwater survey and monitoring procedures described in the PABITRA chapter is not to rank streams but rather to determine whether or not a given stream has an expected natural complement of aquatic species. However, the

information needed to answer this relatively simple question can be applied to inquiries of much broader scope. The use of GIS as an organizer for field data describing physical and biological features of a stream can identify associations over time and space within a single stream or between similar streams. These associations become the basis for recommendations regarding the removal of water without affecting habitat for stream animals or the addition of water for stream restoration. The extension of the GIS model to include an entire watershed establishes the ahupua'a concept (Kamehameha Schools 1994) as the framework for management and conservation decisions among Hawaiian streams. An ahupua'a is a land division used by the early Hawaiians. It encompasses the area from the back and both sides of a valley out into the ocean as far as the seaward edge of the coral reef, and it provided all the resources (food, clothing, shelter, etc.) required by people living in a well-demarcated ecosystem of which they were an integral part.

Status of Fish Surveys

Surveys of native stream fishes have been completed for 177 streams. These represent 47.1% of the 376 perennial streams that occur on the five major islands. Geographical information systems-compatible data compiled from these and ongoing surveys will soon be available for viewing at the Web site for the Division of Aquatic Resources (http://www.hawaii.gov/dlnr/dar).

Mandated Protection for Native Stream Fishes

The decline of sugar cane production in Hawai'i during the past dozen years has prompted demands for the return of water to the windward sides of islands. The most widely publicized example has been the Waiahole contested case, which included 52 d of hearings, testimony from 161 witnesses, and 567 exhibits introduced into evidence (Dingeman 1997). The outcome was the return of water, diverted since the 1920s, back into the basin of Waiahole Stream on O'ahu and a decision in August 2000 by the Hawai'i Supreme Court charging the state of Hawai'i with a requirement to assure "the maintenance of optimum flow for native fishes" throughout the state.

In response to the mandate from the Hawai'i Supreme Court to maintain optimum flow for stream fishes, the Division of Aquatic Resources established three working principles for decision making that would take into account the inability to set precise minimum flow standards because of naturally fluctuating water levels, the importance of recognizing the entire watershed as a functioning ecosystem, and the significance of amphidromous life cycles among the principal aquatic species. Because Hawaii's stream fishes and macroinvertebrates are benthic animals with remarkable species-specificity for occupying discrete habitats within certain sections of streams (Nishimoto and Fitzsimons 1986; Fitzsimons and Nishimoto 1991; Fitzsimons et al. 1997), it is possible to obtain precise information on the nature, size, and location of habitats required by these stream dwellers. Their stereotypic, predictable behavior allows the investigator to focus directly on the animals themselves to determine the effect of removing or adding water to all or part of a stream in lieu of setting arbitrary minimum-flow requirements that would be biologically irrelevant and unattainable. Policies established by the Division of Aquatic Resources for water-use decisions in Hawai'i are (1) no net loss of habitat for native fishes, (2) use of a watershed or ahupua'a approach, and (3) the maintenance of open stream mouths that provide ready access for native species migrating into and out of the sea. The preservation of indigenous stream fishes now has been elevated to the highest possible level of protection in the state of Hawai'i.

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