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Structure of the Division of Aquatic Resources Survey Database and Use with a Geographic Information System

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Abstract

Stream management and protection from overuse are becoming serious areas of conflict in Hawaiʻi. Improvements in the ability to coordinate, synthesize, and communicate information concerning stream animals in over 350 perennial streams is critical to the Division of Aquatic Resources' public trust responsibilities. One of the Division's major concerns is the protection and management of the unique amphidromous fauna inhabiting streams. The native Hawaiian stream animals are distributed throughout the streams in response to elevation and habitat type. A relational database was redeveloped to aid in the storage, retrieval, and analysis of the information collected from years of stream surveys throughout the state of Hawaii. In addition to redeveloping the database system, the Division of Aquatic Resources coded all stream segments to allow integration with a Geographical Information System. Combining survey observation information from the database with data layers showing stream characteristics such as waterfalls, intermittent and channelized sections, diversions, etc. provides insight into important factors affecting the distribution of native and exotic animals within the stream. This paper reports on the current iteration of the Division of Aquatic Resources Survey Database. Additionally, we describe how the data can be integrated with a Geographical Information System program and provide an example of how the database information may be used to answer important questions about the distribution and habitat use of Hawaiian stream animals.

Introduction

The State of Hawaii's Department of Land and Natural Resources (DLNR) has a leading role in watershed ownership and management responsibility. Essentially all of the State's streams arise in forest reserves or other state-owned areas. These fresh waters are important in providing essential habitat for Hawaii's aquatic flora and fauna. As part of the DLNR, the Division of Aquatic Resources (DAR) is tasked with upholding the public trust by ensuring that Hawaii's aquatic resources are managed for the benefit of current and future generations. One aspect of this public trust is the protection of Hawaii's native aquatic animals and the assurance of their long-term population viability. As the development of Hawaiʻi increases and diversifies, so does demand for fresh water. Stream management and protection from overuse are becoming serious areas of conflict in Hawaiʻi, and improvements in the ability of DAR to coordinate, synthesize, and communicate information concerning stream animals in over 350 perennial streams is critical to DAR's public trust responsibilities.

One major concern for DAR is the protection and management of the unique amphidromous fauna inhabiting the streams. The amphidromous animals include fishes, crustaceans, and mollusks.

Amphidromy is a type of diadromy where the adult animals live and reproduce in fresh waters, while the larvae develop in the ocean (McDowall, 1997). Critical to the existence of amphidromous animals are suitable instream habitat, a pathway between instream habitat and the ocean during migratory events, and suitable conditions in the ocean for the developing larvae (Fitzsimons *et al.*, 2002). Current management focuses mostly on the protection of critical instream habitats and the maintenance of the migratory pathway, as these two areas are presumed to be most susceptible to disruption by human activities.

Recognizing the need to protect and manage this valuable and limited resource, the State Commission on Water Resources Management (CWRM) initiated the Hawai‘i Stream Assessment (HSA, 1990) through a cooperative agreement with the National Park Service in 1988. This Program, established in response to the National Wild and Scenic Rivers Act, assisted states in determining the needs and opportunities for establishing state and local wild, scenic, and recreational rivers areas (16 USC 1271-1287, Public Law 90-542, Section 11(a), 1968).

The primary task of the HSA was to identify streams appropriate for protection based on a broad-based collection of existing information on Hawaii’s rivers and streams. The results of the HSA effort provided a reference to help policy makers, resource managers, developers, scientists, and the interested public to:

- locate published information for a particular stream;
- identify and prioritize areas where information is needed;
- understand stream resources within a statewide context;
- make management decisions based on available data;
- develop general stream resource protection guidelines; and,
- identify specific streams appropriate for protection and enhancement.

After the completion of the HSA effort, DAR and many cooperators developed appropriate biological survey methodologies (Baker & Foster, 1992; Nishimoto & Kuamo‘o, 1997; Fitzsimons *et al.*, 2005; Parham, 2005), surveyed many streams, and supported a wide range of research to better understand the life history dynamics of the stream animals. With the increased efforts and the baseline information from the HSA, issues of data storage, timely reporting, and the distribution of results became important.

This information is critical to DAR’s ability to comment on the many surface water development proposals that will divert water from or otherwise modify stream habitats and, therefore, potentially affect stream animals.

The need for managing, conserving, and protecting Hawaii’s native stream biota and their habitats led to the development of a database system to store and retrieve stream data in 1991. The initial design of the database was in FoxBASE+ on a Macintosh platform (Fox Software, 1989). This design was abandoned because it required too much programming experience, and thus did not support DAR’s need for an easy to use database. The next generation of the DAR database was developed in the relational database in ACIUS 4th Dimension (ACIUS, 1987). The data was transferred to this software in part to ACQUIRE the capabilities of 4th Dimension to import/export modified FoxBASE data.

In 1998, the stream database was transferred yet again, this time to Filemaker Pro 4.0 (Claris, 1998). This conversion was done in part because Filemaker Pro 4.0 was upgraded to include relational database functions, was in more universal usage than 4th Dimension, required less storage space, and provided more flexibility in data searches.

In 2001, the database was redeveloped in Microsoft Access (Microsoft Corporation, 2000) on a Windows platform. The redesign of the database was prompted by two major needs. First, the functionality of the database needed improving to speed data entry, management, analysis, and to allow internet access to the data by the public. Secondly, the design of the database needed to be spatially explicit to allow data integration into a Geographic Information System (GIS) that was not easily accomplished on a Macintosh system.

The goal of this paper is threefold. First is to provide an update on the current iteration of the DAR Survey Database. Second is to show how the data can be integrated with a GIS program, and third is to provide an example of how the database may be used to answer important questions about the distribution and habitat use of Hawaiian stream animals.

Results

Current Database Design

The current iteration of the DAR Survey Database was designed to fit a spatially nested hierarchical structure. At the largest spatial extent, the hierarchy begins with the Hawaiian island chain. Nested within the island chain, at increasingly smaller spatial extents, are the individual islands, hydrographic units within an island, watersheds and their streams within a hydrographic unit, stream segments within a stream, survey locations within a stream segment, and individual observations within a survey location (Fig. 1). This basic structure provided the ability to incorporate different survey designs within a single database and allowed for the integration of data collected from multiple different research projects.

At the largest spatial extent, the island chain level provides little direct application to general users of the DAR Survey Database but will allow this database and its structure to be distributed to other Pacific Islands with minimal change. Given Hawaii's leadership role in the Pacific island community and the ability of the database to incorporate a wide range of survey types, use of this database will aid other island groups with their aquatic resource management. Additionally, the island chain level will allow future large scale comparisons to be made to better understand the general patterns in species distributions and overarching commonalities in effective resource protection (Fitzsimons *et al.*, 2002; McDowall, 2003).

At the next smaller spatial extent, the island level provides the ability to compare and contrast the habitat use and distributions of aquatic organisms among islands. The islands that make up the Hawaiian Island chain vary greatly in age (Grigg, 1988) and with the differences in age is a corresponding change in typical stream morphology and available instream habitats (Parham, 2002).

The hydrographic unit is the next level within the nested hierarchy. These units are regional drainage areas established in the 1970s in part by the U.S. Geological Survey (USGS) and the State of Hawaii Division of Water and Land Development. There were 27 hydrographic units on the main Hawaiian Islands, and these are groups of spatially contiguous watersheds that share similar environmental conditions. At this level, differences in general conditions of groups of streams can be addressed.

The watershed is the next level within the nested hierarchy. The watershed is the runoff basin for a single stream. As a result, the watershed and the stream are contained at the same level in the database and made practically interchangeable in a structural sense. The level is called the watershed level as the stream is part of the overall watershed. The definition and use of the watershed label is undergoing changes in Hawai‘i. In the past, the watersheds were only defined for perennial streams, and areas without perennial streams may have been grouped into watershed regions. Currently all watersheds, as defined as the upstream runoff basin terminating at the ocean, are being coded for all watersheds of non-perennial streams in the state. To ensure consistency with older version of the data, all codes for both the old coding systems and newly created coding system have been retained. Comparisons at this level include the obvious stream by stream comparison, but also comparisons of streams with varying levels of modification within the watershed. Collections of larval fishes either emigrating out of or immigrating into the stream near the stream mouth can be linked at this level, as the sample is a representation of potential upstream populations. Additionally, marine or estuarine surveys in the area extending out into the ocean from the watershed edges can be linked to the watershed level. This will allow comparisons of species populations in areas with differing freshwater contributions.

The stream segment is the next level within the nested hierarchy. Stream segments were defined

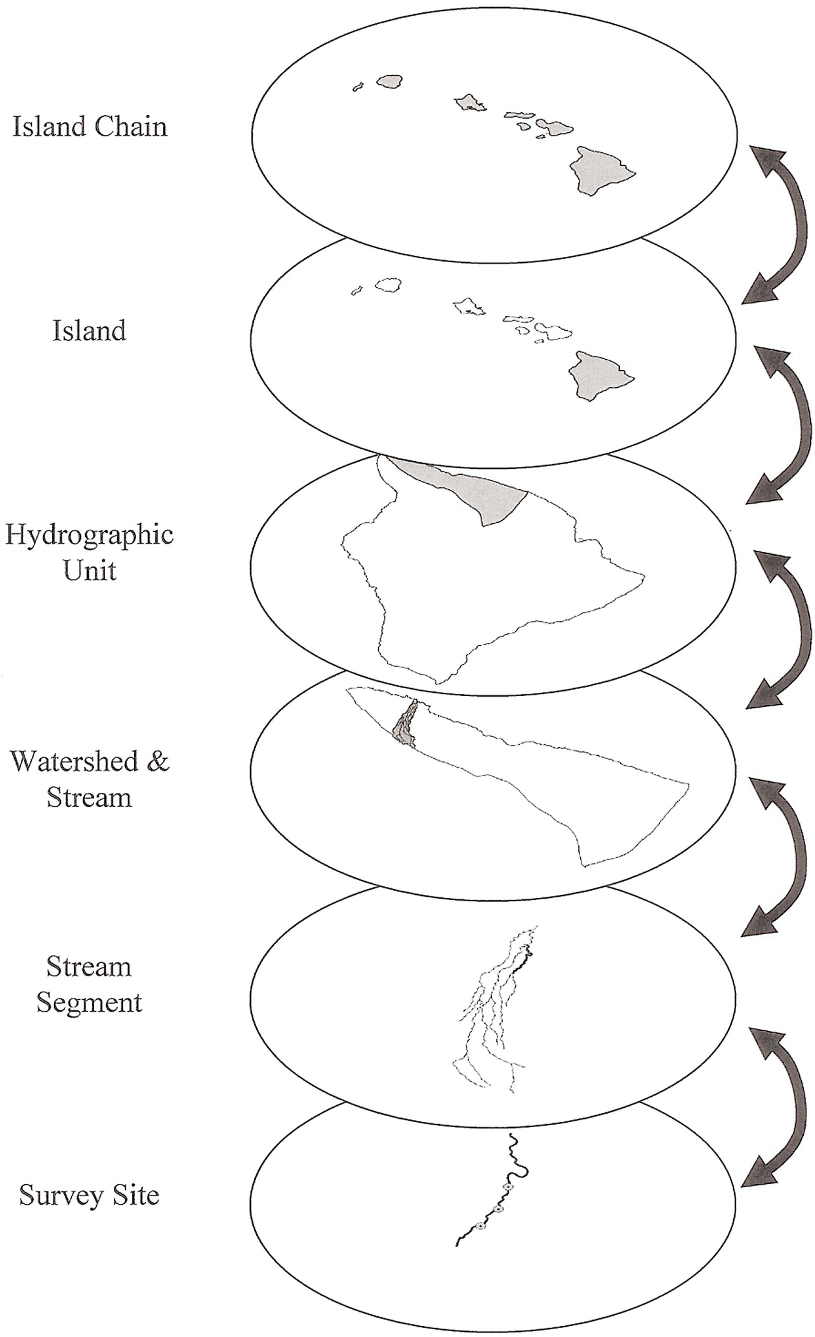

Figure 1. The spatially nested hierarchy used in the Division of Aquatic Resources Survey Database.

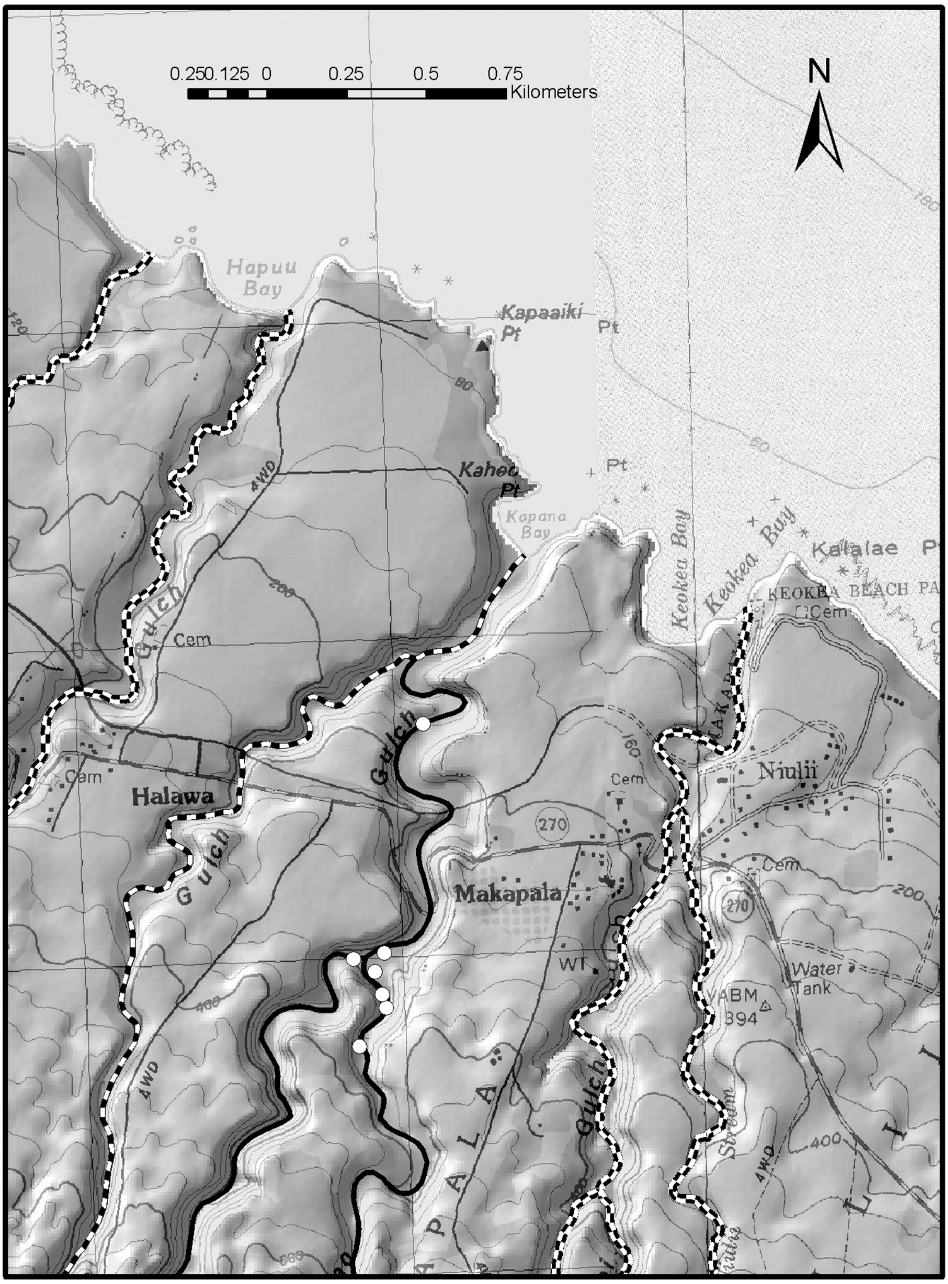

Figure 2. ʻAʻamakāō Stream in Kohala displayed with hillshading and digital raster graphics added. Nonsurveyed stream segments (dotted line), stream segments surveyed but no *Lentipes concolor* observed (dashed line), segments with *Lentipes concolor* observed (solid line), and the individual survey points are displayed.

as any linear, undivided segment of stream. This definition results in a stream segment being coded as a unique segment where the downstream node terminates at either the ocean or the next downstream segment, and the upstream segment terminates at either the end of the stream channel or at a junction with another segment. In the simplest case, a stream could contain just one stream segment if the stream contain no tributaries. The current stream network derived from USGS digital line graphs is based on their 7.5-minute topographic maps. Fields containing the DAR coding as well as their corresponding names were added to the attribute table. The stream segment level within the database has undergone the most changes as the coding system is completely updated to include all stream segments within the stream coverage. This level is likely to continue to undergo changes as higher resolution flow networks will allow systematic coding of all intermittent and perennial channels with a stream system. As in the watershed level, past coding systems were retained along with newer coding systems to allow for backward compatibility within the database system. Comparison developed at the stream segment level includes positional comparison (distance from the ocean, upstream area, etc.) of species distributions within a stream and quantification of extent of segments surveyed. This level is also appropriate for linking to general reconnaissance surveys where long sections of streams are surveyed without specific sampling locations.

The next level within the spatial hierarchy is the site level. The majority of surveys link to the database at this level. The site level requires higher positional accuracy than the stream segment level, and typically has a GPS coordinate location recorded with the site. Given the difficultly of obtaining satellite fixes in some of the deep gorges containing streams in Hawai‘i, it is critical that stream segment information is recorded in the field. Sites usually can be relatively accurately georeferenced after the surveys if the stream segment, elevation, and a few sites during the sampling effort received GPS locations in the field. It is important to understand that a GPS location alone is not always enough to locate the site within the appropriate stream segment. Horizontal error in the GPS reading and errors in the digitizing of the stream segments may result in a situation where the point location is closer to the incorrect stream segment than to the correct one. This is especially common near tributary junctions.

The site is the smallest spatial extent within the database and can be used in a number of ways. The site shows the location that individual species were observed and allows for repeated sampling to see if there are changes over time. The site also holds information on site attributes like water depth or habitat type to allow comparison of habitat use vs. habitat availability.

Numerous additional tables exist or could be added to the database, but these tables will primarily hold information on the species observed in the surveys. These tables can be linked to the overall nested spatial hierarchy of tables at the appropriate level of spatial resolution. Currently, the data date back the 1960s and includes information on perennial and intermittent streams, lakes, reservoirs, ponds, ditches, and diversions.

Linking the Database to GIS

As a result of the design of the DAR Survey Database around a spatially nested hierarchy, linking the data to a GIS is relatively straightforward. A GIS in its simplest description is a spatial database, where each piece of information can be located on a map. While the DAR Survey Database could be fully replicated in a geodatabase, the intention was not to require the use of a GIS in data entry, storage, or access, but to allow full integration with a GIS when needed.

As a concurrent effort to the redesign and development of the DAR Survey Database, the spatial data layers for the streams of Hawai‘i were updated to include all of the necessary location fields to allow seamless integration with the DAR Survey Database. Each of the levels from island to stream segment had attribute fields with data added to the stream coverage, so that a unique location field in both the database and the stream coverage existed for each level. To add the database information into a GIS, the location field of the table must be included with any attribute information in a query. The resulting database file can be linked to the comparable location field in the GIS coverage, and then the results can be displayed in map form within the GIS.

By integrating the database information with the GIS, we can relate information observed in a relatively small location with conditions not only nearby, upstream, or downstream of the sampling location, but to the watershed, region, or island as well. This provides the resource manager a mechanism to aid in determining the positive or negative effects of changes to the environment on the stream ecosystem.

An example of database and GIS integration

In order to display the data from the DAR Survey Database in the GIS, database queries are needed to be developed to extract the relevant information. In order for these database queries to be linked to the GIS, the query must contain a related location field to join the information. In the DAR Survey Database, the location fields are generally codes. The codes remain static within the database, but as new information on a particular area is acquired, the data can be updated without disrupting the database structure. These codes occur only once in the database so there is no chance of the information being duplicated.

In the example query for this paper, the first database query was developed to find all the tributaries in the state, followed by a query to list all tributaries that had at least one point quadrat survey. Finally, from the tributaries that were surveyed, a query was developed that lists the tributaries that recorded the presence of *Lentipes concolor*.

In this example, the first query resulted in 4,988 segments contained within all Hawaiian streams. From the 4,988 perennial segments, 282 (5.6%) had at least one point quadrat survey. Of these, *Lentipes concolor* was present in 132. The total number of point quadrat surveys as of 17 June 2004 included 6,574 individual surveys (Sakuda, 1989–1994, Devick, 1995–2004). Of the point quadrat surveys 1,538 or 23% showed the presence of *Lentipes concolor*.

After the appropriate queries were created and exported from the database, the next step was to import and display the information in the GIS. The perennial stream coverage, named darstreams, can be obtained from the Department of Business and Economic Development and Tourism (DBEDT), Office of Planning (OP) GIS dataserver at http://www.hawaii.gov/dbedt/gis/download.htm. The attribute table for the darstream coverage includes all location fields necessary for linking to the database at all levels of the spatially nested hierarchy. In the example, the join was based on NDAR_CODE field from the darstreams coverage and the DAR_CODE from the database table. Additionally, the individual survey points can be displayed by using the coordinate fields Lat DD and Long DD. After developing the queries and linking the appropriate location fields, the data can be displayed in the GIS (Fig. 2).

Conclusions

The Division of Aquatic Resources has redesigned a relational database to make survey information available to interested parties. The information is available over the internet at http://www.hawaii.gov/dlnr/dar/streams/stream_data.htm. The database allows for efficient integration with GIS software packages and supports a wide range of survey methodologies. The example showed the ability to take the information from the database and link it in several different ways to the GIS stream coverage. The important concept is to use the location fields of the spatially nested hierarchy and be able to correctly link the database to the GIS. In addition to the location fields, the attributes fields are important as they allow the display of many different types of information. These attributes are limited only by the information collected by the surveyors.

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