Database and Offline Tracking System of Kauai's Natural Area Reserve Systems Natural Resource Management Activities

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Abstract

Kauai's unique and extremely diverse and fragile ecosystems requires a range of natural resource management duties to ensure continued protection of a range of plant and animal species, many of which are endangered, in specific areas. Geospatial technologies play an important role in aiding crucial management decisions through tracking, monitoring and analyzing management practices. Of these, web-based mapping and mobile technologies are of increasing importance. The objectives of this study was to streamline offline data collection efforts that could sync with an online database to allow for real-time access of information while in the field to enhance the management decision making process, provide post-analysis capabilities and the generation of reports. To accomplish this a GIS system was designed and developed that utilizes server technologies and includes a collector app that is currently being tested by field crews. I will highlight the challenges we encountered during the different phases from design to implementation as well as the benefits of the system by using examples of how managers are using this to monitor up-to-date management activities and the generation of reports detailing the progress of programs activities.

Background

Conservation and Land Management in Hawaii

The Natural Area Reserve Systems was established in 1970, but was not implemented until 1987 by Governor Waihee and the Legislature (Hawaii Heritage, 1989). As stated on the State of Hawaii's Department of Land and Natural Resources, Division of Forestry and Wildlife's Natural Area Reserve Systems (NARS) website, the NARS program was "established to preserve in perpetuity specific land and water areas which support communities, as relatively unmodified as possible, of the natural flora and fauna, as well as geological sites, of Hawaii." (State of Hawaii, 2013). Hawaii is the most isolated islands on the Earth, and Kauai is the oldest of those main Hawaiian Islands and therefore its plants and animals have had the most time for new species introduction and time for some of those species to undergo adaptive radiation. Kauai's highest point is 5,242 feet and located at the center of the island. At one point Mt. Waialeale was named the wettest spot on earth with an average rainfall of 11,700 millimeters. The high endemism that Kauai has is very unique and contributes to the high number of endangered species. Kauai has 629 native Hawaiian vascular plant flora with 81% endemism, and 219 single island endemic species (Gustafson, 2014). Currently, under the US Endangered Species Act there are currently 443 listed endangered plant species, of which 155 exist on the island of Kauai, with an additional 78 species listed as a species of concern. In addition to these plant species listed there are also many animal, mammal and invertebrate species listed as endangered (USFWS, 2016).

Kaua'i's unique climate and terrain contribute to presence of a variety of diverse ecosystems which range from dry lowland forests to koa-ohia dominated mesic forest to wet montane bogs (Wagner, 1999). Kauai has two Natural Area Reserve Systems, Kuia and Hono O Na Pali (State of Hawaii, 2013) each with its own uniqueness. The map below, Figure 1, shows the island of Kauai and the location of the two Natural Area Reserve Systems.

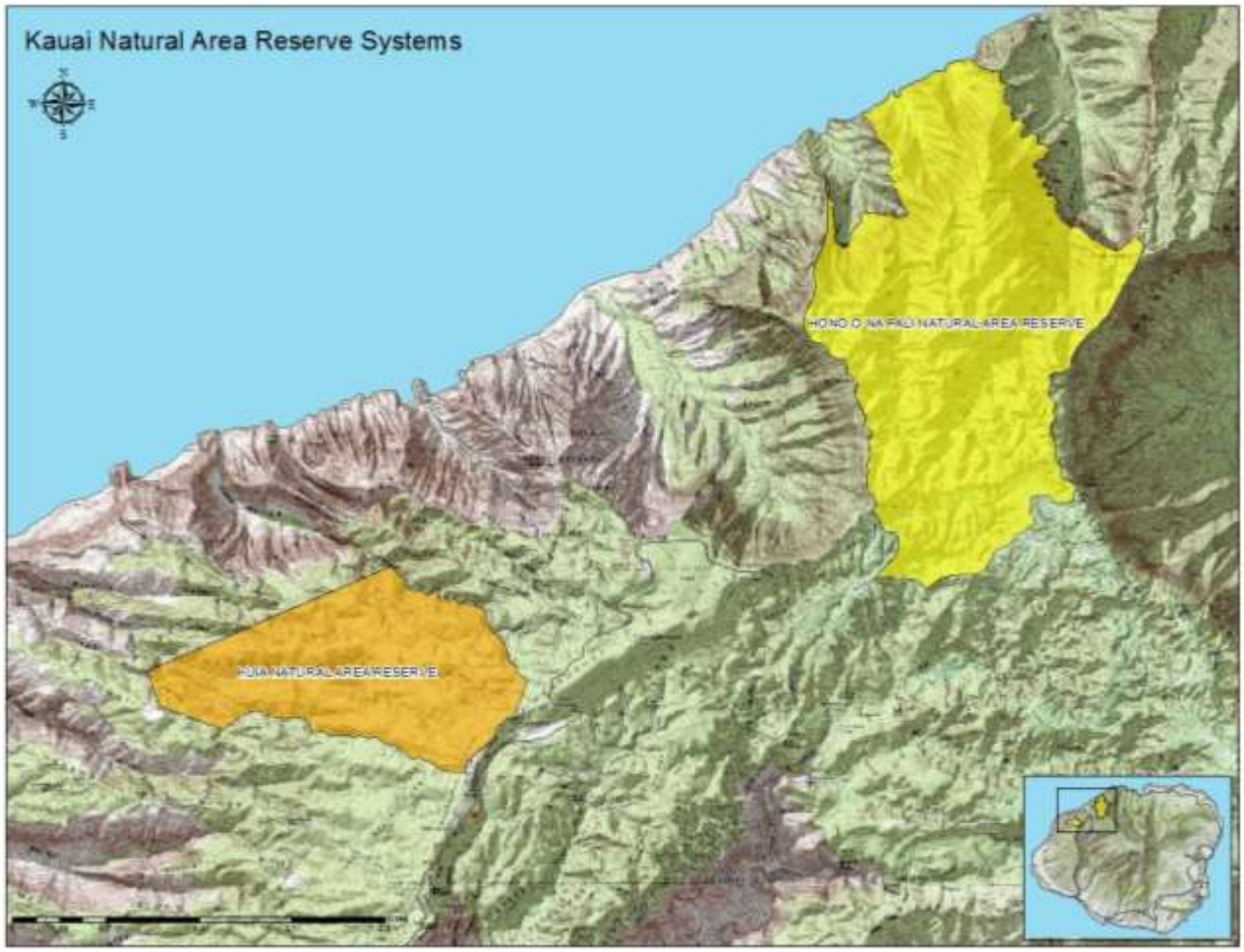

Figure 1. Kuia NAR shaded orange is located on the more west side of the island, where Hono O Na Pali, in yellow, is more northerly. Neighboring the reserves are Na Pali Kona Forest Reserve (surrounding Kuia), Alakai Wilderness Preserve (South of HONP), Kokee State Park (southeast of Kuia and south west of HONP), Na Pali Coast State Park (Northwest of HONP and West and Northeast of Kuia), and private lands owned by the Robinson family and Alexander Baldwin.

Kuia Natural Area Reserve System (KUIA NAR)

KUIA NAR was established in 1981, occurs between 2,000' and 3,900' elevation, is approximately 1,636 acres and contains five distinct native natural communities two of which are considered rare (State of Hawaii, 2012); Kauai diverse lowland mesic forest, Koa/'Ohi'a mixed montane mesic forest, A'ali'I lowland dry shrubland, Koa/'Ohi'a lowland mesic forest and 'Ohi'a/Uluhe montane wet forest (Hawaii Heritage, 1989). As of 2012 Kuia contained 160 native plant taxa of which 54 were listed as rare and/or endangered, and 9 animal taxa, where 1 is rare (State of Hawaii, 2012). A management plan was created in 1989 to assist the Natural Area Reserve Program with prioritizing resource management activities and addressing the current threats to the ecosystems and all of its inhabitants (State of Hawaii, 1989).

Hono O Na Pali Natural Area Reserve System (HONP NAR)

HONP NAR "was designated in 1983 and expanded in 2009" by executive order 3161 and 4270, as stated in the Hono O Na Pali management plan. It includes approximately 3,579 acres and is unique in that it ranges from sea level up to its highest peak (Pihea vista) at 4,284 feet. The original 1989 Hono O Na Pali management plan describes the nine natural native communities; Hala coastal mesic forest, Hawaiian continuous perennial stream, Kawelu coastal dry cliffs, Kawelu lowland mesic cliffs, Kukui lowland wet forest, Lama/Ohia lowland mesic forest, Ohia/Lapalapa montane wet forest, Ohia mixed montane bog, Ohia mixed shrub montane wet forest, and Ohia/Uluhe montane wet forest. Out of these nine, three are considered rare (State of Hawaii, 1989). In the updated 2011 plan, there lists 118 rare plant taxa and the reserve is designated under USFWS Critical habitat ecosystems for 69 of those (USFWS 2004; USFWS 2010).

Threats to Hawaii's ecosystems and natural resources

Alien animal and plant species have been threatening the native ecosystems and natural resources since the first arrival of Polynesians where their habitation of lowlands impacted the natural habitats (Gustafson, 2014). Feral pigs *(Sus scrofa),* goats *(Capra hircus hircus)*, black-tailed deer *(Odocoileus hemionus*), rats *(Rattus rattus, R. norvegicus, R. exulans)*, mice *(Mus musculus)*, and cats *(Felis catus)* are all predators that threaten the natural communities on Kauai (State of Hawaii, 2010).

Although there are several hundreds of invading species the feral pig (*Sus scrofa*) is perhaps the most destructive to intact native forest ecosystems (Browning, 2008). Feral pigs' behavior leads to the loss of native Hawaiian habitat and biodiversity, contributes to the rapid invasion of non-native plant species and increased soil erosion. Feral pigs' destructive behaviors include rooting, browsing, digging and trampling on native forests (Cuddihy and Stone 1990). Feral pigs have a long range of habitation which is influenced by the food source as well as the accessibility of hunters. Hawaii's hunting areas have issues of access and therefore feral pigs can inhabit areas relatively inaccessible to hunters, the only predators to feral pigs (Browning, 2008). Feral pigs as well as all other ungulates and predators play a critical in the spread of non-native plant species as hitchhikers or through the digestive tracts (State of Hawaii, 1998).

Feral goats and black-tailed deer browse on plants causing mortality in native Hawaiian plants which are extra sensitive to browsing. Goats overgraze native plants and disturb soil through the removal of plants, creation of trails and loitering. Increased soil erosion of these disturbed areas by rain and wind contribute to land and rock slides (Yocom, 2009). Black tailed deer are a subspecies of mule deer from the mainland and 40 were introduced on Kauai in 1961 into Pu'u Ka Pele Game Management area (HCA, 2007).

Other predators like cats, rats and mice also threaten the habitat and its inhabitants. This presence of alien rodents in Hawaii creates a plethora of impacts on the environment, water and natural resources. Rodents have been shown predating on native Hawaiian plant seeds and can inhabit an area of 1-4 hectares (Shields, 2007). They, along with feral cats, also readily predate on forest birds and seabirds.

The other top threat besides the feral ungulates is non-native invasive plant species. Invasive species destroy the native forests and displace its inhabitants. Strawberry guava (*Psidisium cattleianum*) is one of the main targets in Hawaii. It crowds out native plant species, creates monotypic stands, reproduces rapidly, and grows aggressively (USFS, 2016). Other invasive plants that alter the environment readily and rapidly are Kahili ginger (*Hedychium gardnerianum*) and Australian Tree Fern (*Cyathea cooperi*). Native Hawaiian plants have a huge disadvantage to introduced species because they have evolved in the absence of most predators and "competitive" species. They grow much slower and are less aggressive, thereby readily being outcompeted by the introduced species (State of Hawaii, 2013).

Other less common, but still devastating threats, are natural disasters. Fires and hurricanes both destroy existing native forests and open space for invasive plants to move in quicker. Fire will tend to destroy a lot of the seeds that may be present in the soil and since they have adapted without these threats, there are very few Hawaiian species that are activated by fire.

Natural Resource Management Activities

To help mitigate these threats and protect the native Hawaiian ecosystems and natural resources, many management activities are performed and will need to continue in perpetuity. The first line of defense is usually the construction of a fence to exclude feral ungulates. These fences need regular checking and maintenance to ensure its effectiveness. Following the installation of the fence is the removal of invasive species, feral ungulates and predators through various trapping efforts and hunting. Once the ungulates are removed and the invasive species plant removal has begun (and will continue as long as necessary) the evaluation of the native seedbank and regeneration begins. Staff regularly collects native plant seeds for propagation or seed broadcast in areas where intense weed removal was performed. Once the plants are grown and ready for outplant staff will transport and plant into the exclosed habitat. In general, these are the main daily resource management tasks. However, it is also necessary to be constantly monitoring and tracking other things like rare or threatened and endangered plants and animals, biocontrols, rain gauges, game cameras, ungulate and invasive plant densities, and other forest trends.

How data is being used to manage the land

- *Herbicide*: data used to help remain compliant with label laws and track effectiveness of treatments to different areas for the different invasive plant species being targeted.
- *Invasive species removal*: track the impact invasive species have on our natural areas, and to record and observe the trends of invasive species introductions.
- *Fence checks:* Ensure regular maintenance is being performed at all fences and is on a regular rotation.
- *Fencing maintenance*: track and record a history of problematic spots to ensure effective fence maintenance. Be able to address potential problems before they happen.

- *Rare plant monitoring*: track and record the history of rare, threatened and endangered plants, assists with timing the seed collection and propagation of plants, and
- *Biocontrol*: monitor the progress and/or on the introduction of biocontrols into new areas
- *Ungulate and predator control*: track ungulate and predator control to show an increase in native plant seed abundance and recruitment or regeneration. Track the number of kills in traps and identify any possible trends.
- *Game camera*: track the presence or absence of ungulates and predators in areas of interest.
- *Native plant seed collection and monitoring*: track the reproductive cycles of native and non-native plants; predict germination rates; increase native seed banking for future restoration projects
- *Native Outplanting*: restore and replenish native Hawaiian plant flora in restoration sites
- *Field staff hours/location tracking:* Generate reports for staff efforts based on location, time and/or management activity; track general personnel details like sick, vacation and comp leave.

Prior to 2014, a field notebook was carried daily and the details were noted at the end of the field day or paper data sheets were filled out depending if the crew remembered to bring them. Due to the weather conditions this did pose the occasional problem. At the end of the week on Fridays the data was then entered in an excel document. GPS' were downloaded from all field staff put into individual shapefiles and saved in one "field" ArcGIS map document. The data was not easily analyzed in this fashion, simply served for record keeping purposes.

Between 2014-2015, an access database was created along with a personal geodatabase. The concept was great but had many limitations and technical issues. Data entry was not simple and there were constant bugs in the database. Waiting for the bugs to be fixed caused a backlog of data entries sometimes weeks at a time. Data and data entry capabilities were not available offline and therefore it was still necessary to have days dedicated to manually entering data at the computer. Doing quality control checks was very necessary as the transition between the data sheets and information entered was frequently mistyped or misentered. Paper sheets were still being ruined or lost or were not legible. When data was finally entered some of the links to the geodatabase allowed for some analysis of these field activities. But mostly only the standard reports that were setup from the developer's perspective.

A huge problem with the notebook data collection is the inaccurate results. Some errors occur because the person entering the data may not have been the one collecting it, and therefore may enter something wrong. There may also be a huge lapse in time between the day the activity was performed and data collected and the day it was entered. It has been shown to be extremely difficult to remember all of the details of the day weeks later. Especially when you begin to add all the details of the days following. It can also be very wet and many

notebooks and paper datasheets were lost to the rain, even write-in-the-rain papers. If write-in-the-rain paper was used, but the wrong pen or pencil was used, the ink can disappear or smudge. These are just a few of the issues that field staff have encountered.

Thus the objectives of this study were to enhance the data collection process by improving the collecting, processing and analyzing of data so that real-time decisions could be made about the type of management practices to use in the protection of endangered species.

To achieve this required several components that included

1. the development of a centralized database system that could be accessed in a variety of ways (desktop, internet and through mobile apps) and allow users to search and retrieve data as well as add and update existing data.
2. The development of a server environment to enable for the connection from different devices to the database
3. The development of a mobile app that could be used while in a disconnected environment in the field.
4. User testing of the application in the field

Development of a centralized database

Current field data collection consists of tracking and monitoring all the natural resource management activities. The first step was to create a file geodatabase which can later be converted to an enterprise geodatabase. This geodatabase housed all the resource management activities as individual feature classes with related tables. Next the geodatabase was customized and published to the program's private ArcGIS Online account. ArcGIS online allows for user sharing settings to be customized so data is protected from the public, or shared to the public if necessary. Utilizing ESRI's ArcGIS Collector App the feature classes have customized attributes which contain a link to "iformbuilder." Iformbuilder is an easy, ready to use program designed for offline data collection. Through ArcGIS Collector the date, ID numbers, group numbers, and other fields that do not change or those that can be automated, are is set up to auto-fill in iformbuilder fields to help minimize typos and to improve time efficiency when collecting information. This feature makes certain that during queries and analysis all data is continuous. A model is show in Figure 2 below.

Figure 2. Models the simple data collection process for offline field data collection.

ESRI's Collector and Iformbuilder are used to record Weed control efforts along with the associated herbicide details. Track Fence construction, maintenance and repair, rare plant monitoring, biocontrol monitoring, ungulate and predator control trap checks and other methods, game camera and rain gauge tracking, native outplanting details, and native plant seed collection information. These above-mentioned activities have associated GPS feature class information and therefore require a GIS feature class and associated attribute data.

ESRI's Survey123 is another developer application that has been extremely useful for the project. It is currently being experimented with using animal sign tracking information and native or non-native plant vegetation monitoring. These are environmental changes that do not have repeatable GIS locations. The location of these changes is always new and therefore can easily be utilized through a survey like format. Although through further research it is shown that it may be possible to include related tables in Survey123 which would allow for all of the GIS features in the geodatabase to also be collected in Survey123 without having to assign a new GPS location every time data is collected.

For tracking activities or management efforts without GIS location data it is not necessary to have an associated feature class and can therefore remain in a simple collection format. Staff, intern and volunteer hours and activities are tracked with Zoho Creator in an online environment.

Through these different, but simplified, data collection processes the field crew can collect and reference information in the field when there is no internet or cell service. Once the data is collected an automated process is set up through another third party service called Zapier. Zapier automatically transfers data between aps through "zaps". The zaps are customized to take all the field data from iformbuilder and import it into Zoho Creator fields. Zoho creator has been great for simple reports to summarize the field data and give overall trend and analysis information for legislative reports. This has allowed the management staff to make key decisions as needed. The ability to customize the data based on time period, locations and specific management activities is crucial for creating timely reports.

Another step that is done on a weekly or biweekly basis is the manual transfer of data from iformbuilder into the file geodatabase. Iformbuilder data is pushed into a csv format and imported into the geodatabase related tables. This allows for an updated geodatabase with all of the location information as well as the collected field observations and activities. Once uploaded into the geodatabase the map is published again into ArcGIS online and all of the Collector App information is updated. Simple webmaps are set up through the program's ArcGIS online account and are available for viewing by staff only. Although staff can view all of the data collected in one Collector map, through the individual webmaps the staff can view data based on different symbology features and the trends are quicker to notice and pin point.

Results and Discussion

A total of 5 years of data was transferred into a centralized database that houses a variety of data such as environmental, species, management application type (date applied, application type).

The table below shows a list of the activities that are recorded daily.

Activity	Description	GIS component
Daily Staff	Hours per daily activity performed	No
Invasive Species Removal	Taxon and Amount	Yes
Native Outplanting	Taxon and Amount	Yes
Volunteer Tracking	Volunteer names and hours contributed	No
Goodnature Trapping	Checks and Rodents removed	Yes
Pig Trapping	Checks and Pigs removed	Yes
Raingauge	Checks and Amount	Yes
Native Plant Seed Collection	Taxon and Amount	No
Wildlife Control Hunts	Hours and Ungulates removed	No
Plant Phenology Tracking	Taxon and Phenological traits	Yes
Invasive Plants and Animals Monitorinng	Taxon and Disturbance level	Yes

The system required the integration of a variety of components.

Figure 3. Visual workflow of the proposed database and collection process.

ArcGIS webmaps was another tool that was utilized to help show at a glance the management efforts of an individual activity. The ability to explore different features on the map and customize the symbology of the features collected has proved useful for managers in creating updated maps. These maps can also be customized for simple, trouble-free exporting.

Zoho creator has proven to be a very user-friendly service that is easily customizable to the data being collected and imported. Standardizing the reports to exhibit continuity between location name, trap names, staff, and dates has allowed for easy analysis. Successful reports and analysis for managers and supervisors have been ongoing for over 6 months. Field staff has provided input to help ease some features of the initial data forms created. It has also been over 3 months since forms have needed to be modified or corrected. Webmaps have also proven successful for management to quickly show and support management decisions.

Through the customizable reports each main management activity has its own report tab, which summarizes all of the data collected to date. Aside from that easier reports have been set up so they can be generated based on time period, which most commonly is monthly reports for the monthly district meetings, and fiscal year for legislative reports. Another useful report has been generated for managers based on location. At each specific location managers

can now see in a table or graph the amount of effort at each site and the details of the information. Graphs that have been created for location or activity can easily be transformed into different graph formats as well as file formats. With one click of a button a pie graph becomes a bar graph, or line graph, or any of the other 15 options. All of the features are easily changed like the axes and data values based on the activities data fields that were collected. Once a satisfied product is created the ability to export data out of Zoho is just as simple. Zoho is built in with option to export data as a CSV, Excel, Pdf, Image or Html. These features are just a few that have made data analysis simple and easy to use at all levels, field staff, supervisors and managers.

The field staff has been collecting data with this system for over 2 years now. They utilize arcgis collector and iformbuilder. Although the field staff had been collecting the raw data it was still crucial to further develop the end reports and final products for the managers and partners. Over those 2 years it was necessary to gain feedback from the crew ensuring that all of the components for each management activity was being captured. It took at least 6 months to find where all of the loop holes may be in in our data forms. Once the raw data was in a format easy for collection and for export, the final reports were created through Zoho Creator. Zoho Creator had an easy to use format of customizing and creating meaningful reports for the managers. The other final product that was used was the ESRI WebAppBuilder. Through the WebAppBuilder managers were able to view the GIS products with the daily updates from the field crew.

Challenges

There were many challenges that occurred during this process. Unfortunately, the initial option to create an Enterprise geodatabase became difficult. With the State of Hawaii system there are many steps for approval and access, and the timeframe did not work out. I did recently receive approval so I am waiting to get it installed and transfer over our existing file geodatabase and see if we can still use the same system but skipping the checking in and out part. Also, the IT department in the state is overworked and has very little time for outside projects, but I will continue to pursue the project and hopefully get it up and running through our State network. Although the server technology at the satellite branches is also not recommended since we do not have IT staff on island, and therefore may need another work around.

One of the biggest things for me was whether or not to use iformbuilder or survey123. Because I've previously tried working with iformbuilder and the program could afford it, I went with iformbuilder. I can see the benefits of Survey123, especially since it is included in the state enterprise license and seems to be very compatible with other ESRI products.

The main downside to the current system is the connection between the data collected and the geodatabase. Also there are too many different programs being utilized, allowing for vulnerability and company stability. Another downfall is the cost of these programs. Currenlty,

annually, Zoho is $600, Zapier $220, and iFormBuilder $2000. These costs will increase as the number of forms or users are added. Zoho creator is not an offline data collection program and therefore the field staff still needs to enter some data in an online setting. Also, it is speculated that through ESRI's WebAppBuilder it may be possible to achieve relatively the same product as Zoho creator, free of cost, through the State Of Hawaii's Enterprise License Agreement with ESRI.

Future goals

Some major future goals for the program is to be able serve high resolution imagery that the program has, through this system and make it available for staff on their current mobile devices. Also to be able to analyze lidar data and serve out the products which can be used for safer field operations. Based on the field data collected and imagery information, it may be possible to begin to make some species model predictions and distributions maps. This accurate spatial data could be invaluable for creating analysis of these small areas of focus in Hawaii. We may be able to predict invasive species dispersal based on all of this information. I would also like to find a way to incorporate our game camera tracking data and photo storage, to better help keep a photo journal of the areas that these game cameras are located.

Technical Details to Accomplish Objectives

For a successful implementation of this project, it is necessary to first assess the technical requirements to ensure they meet the State Of Hawaii's IT and ETS guidelines. The plan, shown in Figure 3, is to set up ArcGIS for server on a local server on the island within the State Of Hawaii DLNR building. If there is no way to accomplish this goal, there are other open source options available to serve the enterprise geodatabase. In the meantime, through user input, in this case is the field staff and resource management staff, the details will be assessed of all the management activities and then an enterprise geodatabase will be created with open source GIS using PostgreSQL. Once the geodatabase is created a link between the geodatabase and ArcGIS Online and the Collector App will be established. It will then be necessary to customize Collector app to streamline data collection for field users. Next using ArcGIS webappbuilder, a web application will be designed to integrate the GIS and geodatabase which will allow management to create standard reports/analysis/queries. An alternative could be to use a program like scriptcase that would allow for data migration from postgresql to a new front end webapp, for easier viewing of management activities.

Following all of this is an evaluation of the success or failure of the system at all levels (user, editor, analysis, manager). This evaluation will be used to go back and make any necessary edits or changes to make the system a success. At this time, it may be ideal to migrate or import the old data dating back to 2012, which can be used for further data analysis.

A backup of the data in SQL will be created and held for future migration into a Microsoft SQL server, which is the long term goal for the State Of Hawaii DLNR.

Data Technical Requirements

1. Enterprise geodatabase creation for all management activities in postgresql
   - Based on user input attributes will be configured for easy data collection in attribute table of each activity
2. Publish to State of Hawaii feature service and serve to "Kauai NARS group" in ESRI's ArcGIS online and later Collector App
3. Creation of web application either through ESRI WebAppBuilder or another open source program
4. Migrate old database systems into new
5. Utilize ESRI Collector App for field data collection (offline)
6. Utilize ESRI Survey 123 App for field data collection (offline) of non-spatial items

Overall this project was a huge success for the program and will be easily customizable as the program continues to grow and expand in management activities.

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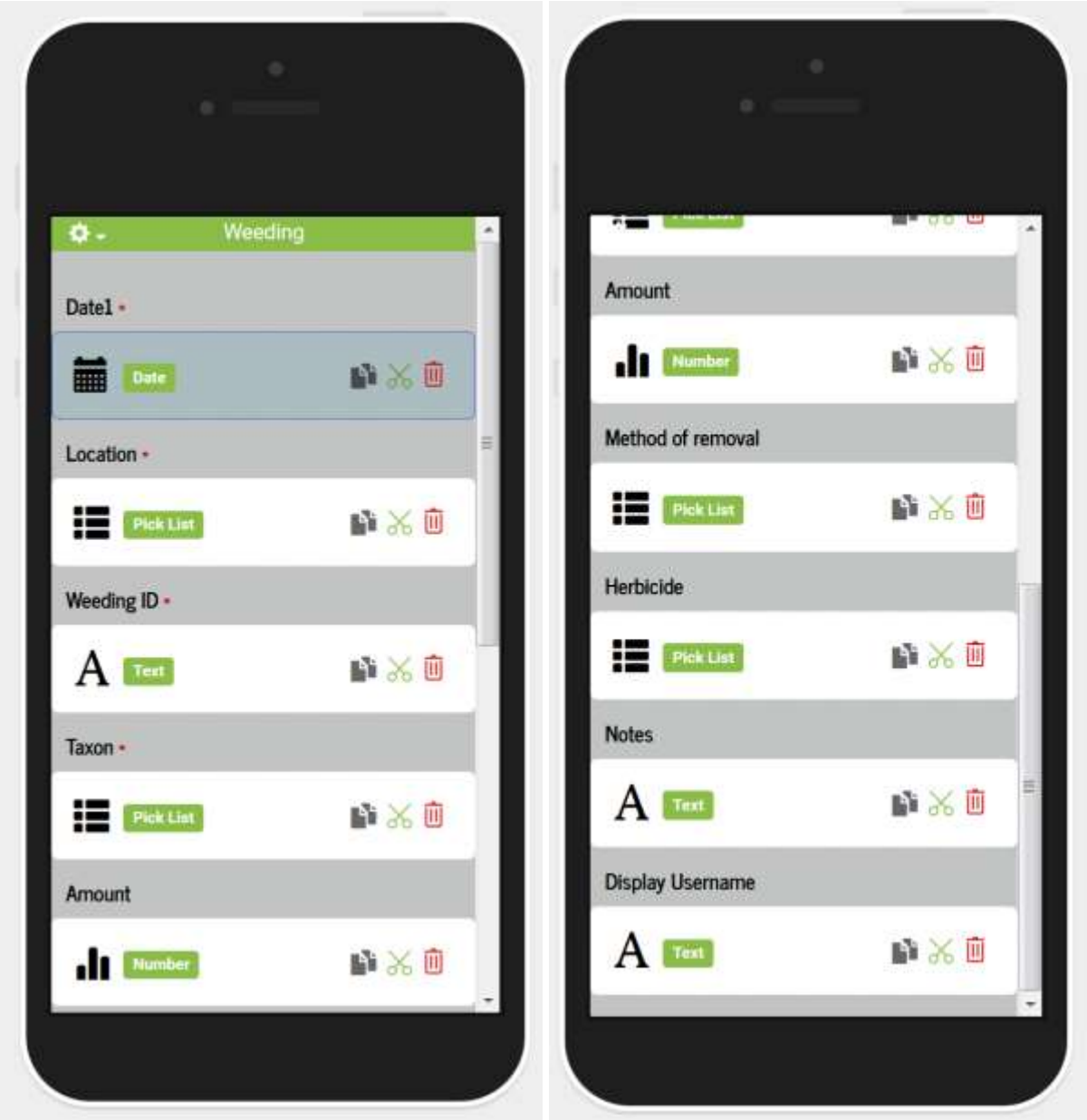
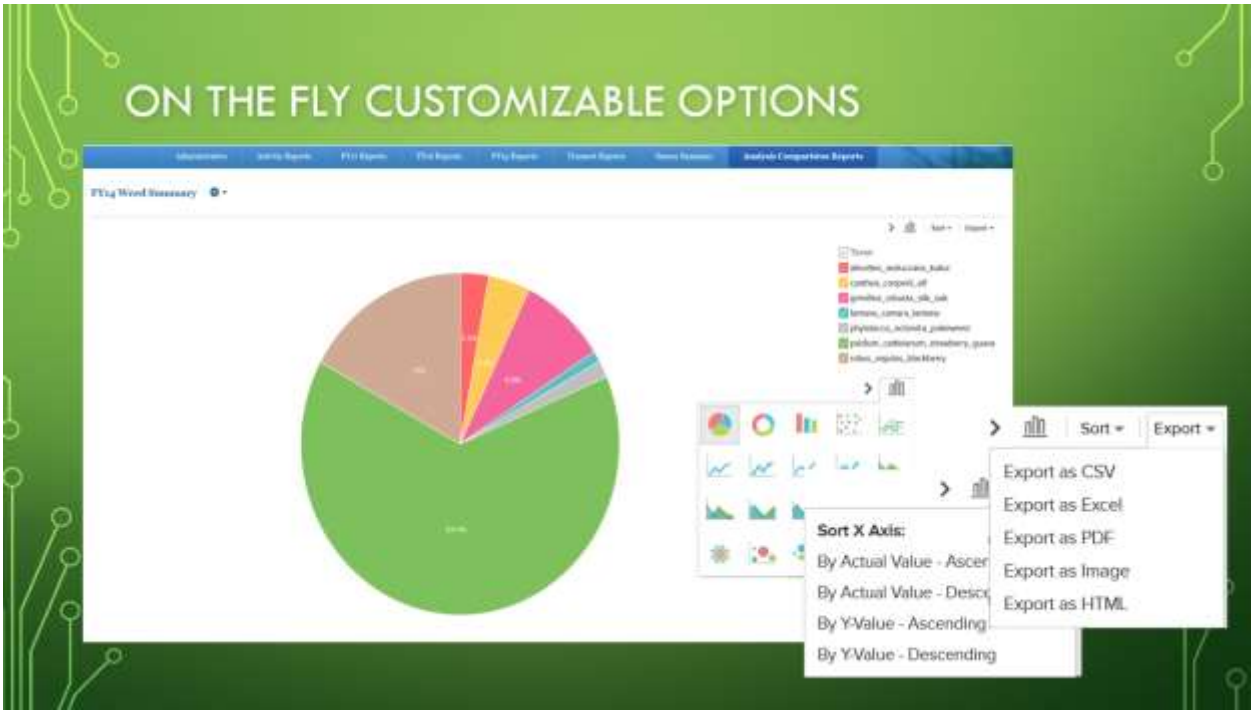
Appendix – Example forms and final products

Example Weeding iformbuilder collection form



Example Weeding efforts Zoho Creator report



Example WebAppBuilder Live Snare Report