A Watershed-Based Approach to Food Security and Sustaining Biodiversity on Yap

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Figure 3. Remnants of an old rock dam at lower end of taro patch.

Figure 4. With the demise of the rock dam at the lower end of the taro patch the banks of drainage channels are eroded away allowing salt water to penetrate further inland. Here salt water has moved some 200 ft. upstream in about the last 25 years.

Figure 5. The once moist taro patch in the foreground has been left high and dry as the rate of fresh water drainage increased due to the deepening of the eroded ditch in the background.

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Figure 13. Here the stream overflowed its banks and scoured out the rich silt needed for taro patches in the background to thrive.

Figure 14. Bernie Mininug adding rocks to a modest retaining wall that prevents the erosion of rich mud from the taro patch which is already starting to thrive. This is an example of Yapese “nature-integrated technology” where people work along with natural processes.

Figure 15. Portion of the project where many trees were removed resulting in rampant growth of weedy herbaceous plants that clog the stream.

Figure 16. Rocks built to protect stream bank at a curve where water flow has more force. A portion of the wall to the right has been damaged by heavy water flow following intense rains associated with passing typhoons.

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Figures 19. The upper portion of the stream becomes steep and rainwater runoff can erode stream banks during heavy rainfall events.

Figure 20. Rockwork was installed to withstand increased water force at curves.

Figure 21. While the community cleared debris from the stream, the culvert appears to be too small to accommodate the fluctuating volume of water flow from streams and is likely to become clogged again.

A Watershed-Based Approach to Food Security and Sustaining Biodiversity on Yap

Executive Summary

In keeping with the Yap Forest Action Plan top priorities of food security, biodiversity conservation, watersheds and development of local capacity, a three pronged approach was used to evaluate Yap's watersheds and their stewardship: GIS, field interviews and village projects.

GIS technology was used to analyze attributes of Yap's watersheds in parallel with a review of relevant literature, field interviews and projects on traditional Yapese methods of using watersheds. One hundred and eighty nine watersheds and interfluve areas were delineated and identified so that data on attributes relevant to food security and biodiversity could be mapped and gathered into a database for each watershed to enable communities to evaluate their watersheds and prioritize watershed stewardship activities.

Field interviews on traditional practices in watersheds were carried out throughout Yap to gather information on traditional use of watersheds and the incidence of taro patches and shifting gardens. Reports on the location and occurrence of salinization of 2,707 taro patches, and locations of 1,959 sites of recent shifting gardens was digitized in order to evaluate food production capacity and its vulnerability to salinization as a result of sea level rise and increased incidence of storm surges associated with climate change. Overlaying these maps with a digital elevation model (DEM) indicated that impacts of salinization are occurring at elevations up to 5 m, much higher than expected. A GIS analysis indicated that some 68% of areas suitable for taro production based on slope and soil types are located at 5 m elevation or under.

Community watershed projects demonstrated the efficacy of managing stream flow to renovate taro production. They also demonstrated a need to augment traditional methods with the use of modern materials in order to accommodate increased water flow due to increases in rainfall predicted to result from climate change. Field interviews and observations revealed a number of traditional technologies for managing water flow and moisture in taro patches and shifting gardens that might be revived to improve food security. Field observations also indicated negative impacts on taro patches and watersheds resulting from the use of heavy equipment in road projects.

Areas designated as being of special biodiversity value (ABS) were demarcated so that watershed stewardship plans can, in the future, include their protection and development into terrestrial protected areas in accordance with Yap's criteria for terrestrial protected areas under the Micronesia Challenge.

Results of this project are incorporated into a series of resource maps and a geodatabase that communities can use to evaluate their watersheds, prioritize watershed activities, and develop watershed stewardship plans and data based proposals for projects.

I. Introduction and Goals

In Yap, sea level rise is causing coastal erosion and salinization of fresh water resources and taro patches, especially in low-lying outer islands. Outer islanders (~40% of Yap's population) are increasingly migrating to mainland Yap. Pressure is growing on local agricultural production and social support systems as coastal food production systems are impacted by salinization at a time when an increase in food production is needed. Agricultural activities will need to be moved upland without damaging biodiversity services of watersheds. Preliminary GIS analysis indicates large areas of highly erodible soils in Yap's uplands. To avoid deforestation and downstream impacts (e.g. sedimentation) on marine productivity, food production systems will need to be relocated based on a sound understanding of watershed processes. Indigenous agricultural practices manage water through systems of taro patches and agroforests while maintaining forest ecosystem services. As activities are moved upland, GIS and science-based analyses are needed to enhance indigenous practices in the face of unprecedented challenges. The Yap chapter of the FSM Forest Action Plan (FAP, formerly the State-Wide-Assessment and Resource Strategy SWARS) describes this problem in maps Y-5 to Y-8 and recommends this project on page 47. A major strategy of the Yap FAP is to turn "Forestry" from the work of a small government agency into a community concern. Therefore, public awareness of watershed processes and services, and community-based tools for watershed assessment are needed. Landowners and communities need to be empowered and supported to evaluate the health of their watershed, address threats, and implement best practices on watersheds. An accurate and current geodatabase for watershed management, as well as examples of best practices, are needed to inform watershed management on Yap.

In keeping with the Yap Forest Action Plan top priorities of food security, biodiversity conservation, watersheds and development of local capacity, the goal of this program is to enable individuals and communities to evaluate their watersheds and prioritize stewardship activities to enhance food security while protecting biodiversity in the face of climate change. Accordingly the goals of this project are to: 1) provide GIS maps and geodatabases to enable communities to evaluate their watersheds and prioritize watershed stewardship activities, 2) access indigenous watershed practices along with scientific literature on watersheds, 3) carry out four community watershed projects, 4) share results with the public, and 5) develop a framework for watershed stewardship planning.

II. Methods

This project required assembling and managing a dedicated geodatabase, which was created using the methods described below.

1. Imagery and Data

Geospatial data were collected from a number of agencies, organizations, and individuals as shown in Table 1.

Table 1. Geodatabases and basic metadata used for this analysis.

File	Source	Date Created	Notes
Image	Digital Globe	2010	RGB WorldView 2 Satellite imagery of Yap relatively free of cloud cover
DEM	USGS	2013	Digital Elevation Model
Yap Outline	Heads-up Digitized	2014	Based on 2010 Digital Globe
Soils	NRCS	1983	Revised 2012
Vegetation	USFS	1987	Used because more detailed than FIA (2006) vegetation map
Slope		2014	Created with ArcGIS 10.2 based on USGS DEM data
Streams	USGS	1983	Modified to align with WorldView2 image
Distribution of Households on Yap	Yap Branch, FSM Statistics Office	2016	Developed from 2010 FSM census data
Yap State geodatabase	Yap State/Queens University GIS program	2001 - 2016	Database is housed at Yap State Division of Land Resources with satellite database at Yap Forestry

The satellite image (Digital Globe 2010) is an ortho-rectified image collecte by the WorldView2 satellite on February 10, 2010, with a resolution of 0.5 m x 0.5 m. Cloud cover is less than 5%.

One of the challenges in working with geodatabases collected from multiple sources is the issue of data alignment. Even with perfect alignment of reference points, the subjective determination of natural boundaries (coastlines, ridgelines, etc.) is difficult and complicates the analytical integration of the data. On small islands, particularly those fringed with terrestrially ambiguous mangrove forests, the challenge of determining the precise location of the island's edge is especially fraught with error. And, since this decision de facto marks the edge of sea level (and thus, the starting point of elevation measurements), the consequences are significant. All efforts were made to maintain original data integrity.

The DEM data (USGS 2013) were originally created by the USGS as part of the National Elevation Dataset with an elevation increment of 1/3 arc-second (i.e., approximately 10 m). The horizontal datum is NAD 83. The vertical datum is North American Vertical Datum of 1988.

Prior to use, the DEM was projected to a WGS 1984 datum and UTM 54N projection. One meter contours were interpolated for Yap from the DEM data using the Spatial Analyst – Surface – Contour tool within ArcGIS 10.2. While there are obvious drawbacks to using this approach (i.e., developing a false sense of confidence in the accuracy in position elevations), we felt the benefits justified the approach. In particular, by estimating elevations, we could generate a qualified description of the elevation extent of saltwater intrusion. As such, our results should be understood to be qualified estimates, not absolute findings. Until finer resolution, higher accuracy elevation data become available, this is likely the best we can do.

The outline of Yap proper was heads-up digitized as a vector file from the 2010 WorldView2 satellite image. Use of this image allows inclusion of shoreline, road, etc. alterations more recent than the often used USGS quad map or the USGS DEM data. At a coarse level, the DEM data align well, but not perfectly, with the WorldView satellite image. In some places (e.g., Dalibebinaw coastline) portions of the island imagery are outside the DEM boundary of Yap (i.e. where pixel values > 1). This precludes these areas from being included in the elevation zones used in subsequent analysis. This misalignment is at least partially due to DEM elevation values being described in one-meter increments. Values of 0 m elevation are considered ocean. Values greater than or equal to 1 are considered land. However, the actual coast does not begin like a stair step. Therefore, land areas between 0 and 1 m elevation are imperfectly captured in the (10 m x 10 m) DEM data. The "actual" coastline, may be either somewhere within the first "1" pixel or within the first "0" pixel. Clearly, the use of DEM data for the type of work conducted in this project comes with a certain degree of caveat emptor.

2. Watershed Delineation

The conceptually simple task of dividing Yap's topography into watersheds proved to be pragmatically complicated. At several points, "best judgment" decisions were made from the guiding principle of producing a map with the most practical application.

Watersheds were initially delineated from the DEM data using the Hydrology tools in Spatial Analyst extension of ArcGIS 10.2. Pour points selected for this procedure were taken from the intersection points of the USGS blueline streams and the DEM coastline. The delineated watersheds followed the DEM-generated stream network. However, the watersheds suffered from hydrologically improbable shapes (e.g., having some portions one cell wide and ten cells long). The watershed boundaries were subsequently manually adjusted to better align with the stream paths visible in the WorldView image. For example, if the USGS streams meandered outside the DEM watershed boundaries, the boundaries were widened. This was done most frequently in low-gradient areas, in which the (10 m) DEM was not able to capture topographical detail driving actual stream location.

All watersheds initially terminated at the edge of the DEM file, in a coastal pixel. Thus, if no pour point was designated, no official watershed was generated. Two steps were taken in response to these methodological limitations: 1) watersheds boundaries were adjusted to terminate at the edge of the WorldView2 image boundary; and 2) Areas not draining to a stream (i.e., land outside of the watersheds), were labeled “interfluves.” Thus, 100% of the land area of Yap Proper was included in the analysis.

Each watershed or interfluve area was given a unique identification number. The numbering system starts at the northernmost area of each island, then proceeds clockwise for that island. The northernmost area of the next island is numbered after e every area in the previous island has been numbered.

3. Mapping of Taro and Saltwater Intrusion

Locations of current taro production and saltwater intrusion were determined by field surveys conducted by Ms. Bernie Mininug of Yap State Department of Agriculture and Forestry August, 2013 to November, 2014. She visited each village asking two questions: 1) where is taro currently grown, and 2) which, if any, taro patches are currently being affected by saltwater? She was given separate section maps (approximate scale 1:5,000) of the 1983 USGS quad map (e.g., Rumung, Maap, Gagil-Tamil, Fanif-Weloy, and Dalipebinaw-Gilman). On each map, she marked the reported location and type (e.g., *muqut, talra, mulbuouch, muqut ni ga*[1]) of each taro patch, as well as whether it was affected by saltwater. The roads, streams, and coastlines on the USGS map sections were used as geographic references by the village member and Ms Mininug to place taro patches on the map section. A digital photo was then carefully taken of each paper section map. These photos were geo-referenced in ArcGIS 10.2 using road intersections and unambiguous coastal points as reference points. Heads-up digitizing was then used to enter the taro patches and saltwater intrusion points into the geodatabase. To increase the accuracy of placement (i.e., relative to streams, roads, and visible landscape features), the geo-referenced maps were displayed at 50% transparency over the WorldView image. *Talra, muqut,* and *mulbuouch* taro patches were entered as point features. *Muqut ni ga* areas were entered as polygons.

In order to obtain a rough estimate of the area of existing taro patches, the average size of each class of taro patch was estimated and used to create a buffer about location points. *Talra* areas were created using a 5 m buffer around estimated points. *Mulbuouch* areas were created using a 15 m buffer around estimated points. *Muqut* areas were created using a 50 m buffer around estimated points. *Muqut ni ga* areas were determined by digitizing field drawings by Ms Mininug. If any areas mapped below the 1 m elevation line, their totals were added to the area 1-2 m total for that type of food production.

[1] Descriptions of types of taro patches are given in section 2.3.

Upon entering the salinization data, it became clear a majority of points were at or below a 5 m contour level. This elevation was then used as a rough guide for creating zones of vulnerability to salt water intrusion: 1-2 m elevation zone was considered “highest risk;” 3-5 m elevation was considered “medium risk;” and above 6 m elevation was considered “low risk.” A summary of the distribution of the four classes of taro patches is presented in Table 2.

During the interviews the general areas where shifting gardens (meliy) have been made in recent times were also roughly mapped. This data was entered into the GIS geodatabased and appear on Map 9 as yellow triangles. Each triangle represents an area where such gardening was done in recent times and generally represents a cluster of gardens rather than individual gardens. In some cases, such as the hills behind Waanyan and Gachepar villages there were more sites than could be recorded. It is estimated that the map represents about 70% of the areas where *meliy* have recently been made. The presence of ditched beds below a forest canopy in other areas indicates that in the past many more areas were gardened.

4. Mapping of Potential Food Production

Three types of food production potential were mapped: taro, shifting (“*meliy*”), and agroforest. Areas considered to have prime potential for taro production had alluvial soils (e.g., Dublon, Dechel, Gitam, and Sonahnpil series) with slopes less than or equal to 20%. Areas considered prime for shifting gardens were those classed as “secondary vegetation” in the USFS vegetation map. Areas considered prime for agroforest food production were those classed as “agroforest” in the USFS vegetation type (Falanruw *et al* 1984). Slope was determined from the DEM file using the Spatial Analyst – Surface – Slope tool in ArcGIS 10.2. The total area of each type of potential food production was summed by elevation band (1-2 m, 3-5 m, and over 6 m) is presented in Appendix 1,Table 4 and illustrated in map 5.

III. Results

Results of this project include: 1. a GIS watershed geodatabase, 2. a survey of watershed literature and Yapese practices in watersheds, 3. four community projects and 4) sharing the project with the public and 5) a framework for watershed stewardship planning. These are described below.

1. A GIS Watershed Geodatabase

A major result of this project is the development of a GIS database and associated maps that can be used to better visualize, understand, rank and evaluate Yap’s watersheds in order to prioritize actions for the most relevant watershed stewardship. The database consists of GIS & other maps, spreadsheets of data on watershed attributes and tables as described below.

1.1. Maps and Imagery

The maps and images produced or utilized in this project and are compiled in Appendix 2. Maps are based on data layers in the Yap GIS database housed at the Division of Land Management. References to these maps are given in relevant sections throughout this report.

General maps and images

1. Satellite image of Yap

2. USGS topographic map of Yap

3. Digital Elevation Model (DEM) of Yap

4. Watersheds of Yap with Reference Numbers

Soils and vegetation maps.

5. General Soil Types (derived from Smith 1983).

6. Yap Vegetation Zones (based on Falanruw et al. 1987), color coded to show major types and some important sub-types

7. Vegetation map (Donnegan et al. 2011)

Maps related to food security

8. Yap Food Production Potential

9. Yap Food Security and Vulnerability to Salt Water (overall map and enlargement of 4 sections of Yap)

Maps related to Biodiversity.

10. Native Forests, including mangroves and terrestrial forests including disturbed forests but excluding agroforests. Some important subtypes such as forests with big trees and forests with bamboo are included.

11. Disturbed and less disturbed forests

12. Terrestrial Areas of Biodiversity Significance (ABS) as demarcated in a series of workshops and published as TNC (2005)

Maps of Threats

13. General Soil Types Vulnerable to Sea-Level Rise and Storm Surge. General soil types with a dark blue overlay indicating zone of 1 meter sea level rise and areas vulnerable to a 5 meter storm surge with a light blue overlay.

14. Yap Mangrove Vegetative Change 2003 & 2010. Map showing general area of mangroves with some dieback and general areas with no notable dieback

15. Fire Behavior Potential under Drought Conditions (from Neil, Rea & Falanruw 2002)

Maps of urban land use

16. Map of households (from Yap office of FSM Statistics Division)

Summary posters

17. Diagram of traditional land use zones

18. Yap Watershed Project. Poster for Yap Day 2014

19. Mapping Yap's Food Security and Vulnerability. Poster for Yap Day 2015 and SPC/EU Sustainable Climate Change Adaptation meeting on Yap 2015

1.2. Geodatabases for Evaluating Watersheds

There are 189 watersheds and interfluves on Yap (Map 4. Appendix 2). Our project calls for prioritizing these watersheds in relationship to their importance for food security and special biodiversity significance. The objectives of food security and biodiversity protection tend to be mutually exclusive; the more areas are developed for food security, the less wild biodiversity they contain. Therefore, in order to assist communities with planning and prioritizing activities within their watersheds, we developed a set of geodatabases that can be used to evaluate potential food production and areas important for sustaining biodiversity. These geodatabases are displayed in Appendices 3 and 4. Appendix 3 displays data organized by Watershed ID numbers and Appendix 4 displays data sorted by major watershed attributes.

1.2.1. Master geodatabase arranged by watershed ID number.

Appendix 2, Map 4 shows these numbered watersheds. The geodatabase spreadsheets provided in Appendix 3 include:

1. Watersheds arranged by ID number with total area of watershed with area of major vegetation types. Descriptions of these vegetation types and their species composition can be found in Falanruw et al. (1987). This vegetation map was used as the vegetation types are more refined and related to local land use than the more generalized vegetation maps produced by the FIA project (Donnegan 2011). This database can be used to assess connectivity between Yap's habitats from ridge to reef. It can also sorted by different attributes in order to rank watersheds by different parameters.

2. Watersheds arranged by ID number with area within elevation zones 1-2m , 3-5m, and 6+ m (the highest point on Yap is 177 m) in both area and percentage of the watershed. This geodatabase can be used to evaluate vulnerability to sea level rise (SLR).

3. Watersheds arranged by ID number with total area and percent of area of agroforest, and percent of agroforest area in 3 elevation zones. This geodatabase can be used to evaluate potential food security and vulnerability of agroforests to SLR.

4. Watersheds arranged by ID number with area defined as an ABS (area of special biodiversity significance), area of established terrestrial protected areas, and presence of an adjacent marine protected area (MPA). This geodatabase can be used to identify ABS and the status of their conservation.

1.2.2. Geodatabase of watersheds ranked by total area, area below 5 m, area of agroforest and area of ABS

This project calls for prioritizing watersheds in relation to their importance for food security and special biodiversity significance. This helps communities to compare their watershed with others on Yap and to prioritize watershed activities. These database spreadsheets are found in Appendix 4 and include:

1. Watersheds ranked by total area with area of major vegetation type
2. Watersheds ranked by percentage of area below 5 m
3. Watersheds ranked by total area of agroforest with area and percentage of area of agroforest below 5m
4. Watersheds ranked by area of TNC terrestrial area of biodiversity (ABS),with presence of a DAF/Yap CAP terrestrial protected area (TPA) and presence of a marine protected area (MPA) has been established adjacent to watershed

1.2.3. Tables summarizing data

A number of tables summarize data on:

1. Geodatabases and basic metadata used for this analysis (Section II 1.)

2. The 4 largest mangroves and associated watersheds (Appendix 1)

3. Total area for taro production on basis of soil type and slope within 3elevation zones (Appendix 1)

4. Estimated area of mapped taro patches within 3 elevation zones (Section III.2.4.1.)

1.3 Using the Geodatabase

Landowners and communities can use the maps and other imagery to gain a view of a watershed's attributes. They can zoom in on any watershed of interest to gain a view of the attributes and utilize the geodatabase spreadsheets to obtain numerical data on these attributes. The spreadsheets on watersheds ranked by various attributes can be used to see how their watersheds compare with others. These data can then be used to evaluate food security and biodiversity.

1.3.1. Watersheds and food security

The traditional Yapese food production system has three main components: diverse agroforests, taro patch systems and *meliy* gardens. Of these three main food production systems, only agroforests can be mapped using aerial imagery. Inasmuch as agroforests often include taro patches and interspersed *meliy* gardens, the area of agroforest gives a general indication of food security.

Appendices 3, 3.3 and 4.3 provide data on the total area of agroforest per watershed and the area of this agroforest that lies within elevation zones 1-2 m, 3-5 m and above 6 m above sea level. Appendix 2, map 6 shows the occurrence of agroforests throughout Yap, while Map 8 shows the location of agroforests and areas suitable for *meliy* gardens and taro patches in relation to their vulnerability to SLR.

In addition to the analysis of mapped agroforests, this project undertook the mapping of taro patches and *meliy* gardens based on field interviews. Results are shown in Appendix 2, maps 9a-

e. This important component of the project is discussed in section 2.4, and summarized in Table 2.

Appendix 1, table 4, indicates the area suitable for taro culture based on slope and soil type in three elevation zones. Note that some 68% of the area suitable for taro culture lies within 5 meters of sea level! This finding is further discussed in section 6.1.

1.3.2. Watersheds and sustaining biodiversity

The FSM government and Yap State have committed to the Micronesia Challenge to effectively conserve at least 30% of near-shore marine resources and 20% of the terrestrial resources across Micronesia by 2020. The definition and criteria for areas to be managed to sustain biodiversity is to be determined by each State. Yap's portfolio and criteria for Terrestrial Protected Areas (TPAs) is attached as Appendix 5. To assist Micronesian entities in choosing areas with special biodiversity significance, the Nature Conservancy held a series of workshops throughout the FSM that resulted in "A Blueprint for Conserving the Biodiversity of the Federated States of Micronesia (TNC 2003). This publication included maps delineating "areas of biodiversity significance", or "ABS". Map 12 shows the ABS for mainland Yap.

Inasmuch as almost all land and marine areas of Yap are private property, the designation of areas to be effectively conserved such as Marine Protected Areas (MPAs), Locally Managed Marine Areas (LMMAs) and Terrestrial Protected Areas (TPAs) is up to estate owners[2] and communities. The local Yap Community Action Program assists communities with MPAs and

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[2] Traditionally on Yap, resources are owned not by communities but by specific estates in a complex system that includes many checks and balances. While many Pacific cultures are classified as "matrilineal" or "patrilineal", Yap is known among anthropologists for recognizing both the male line and the female line. Thus while the patrilineal line may "own" and use resources, the matrilineal line also exerts controls. Estates, are organized into ranked systems of villages and larger networks throughout Yap culminating in three paramount estates (Lingenfelter 1975, Labby 1973). For administrative convenience, foreign administrators organized Yap into the ten municipalities that are recognized today.

Today it has become fashionable to refer to "grass roots" activities in conservation and as "community management". This ignores the complexity of the traditional resource use and management system on Yap, and carries an inherent danger that "community management" may come to be interpreted as "communal management", thus introducing the potential "tragedy of the commons" in which resources available to all are used up or destroyed. The term "community management" does however, serve to indicate activities that are undertaken by people with vested interest in sustaining the resources that benefit the community as a whole. This is consistent with a basic tenant of Yapese culture that stipulates that individuals should place the welfare of the community first. Thus for the sake of brevity, this report uses the term "community" as a surrogate (stand-in) for Yap's complex traditional system of resource tenure. It also allows watershed stewardship plans to apply to individual estates, community areas and municipalities as the case may be.

Yap State Forestry within the Division of Agriculture and Forestry (DAF) assists communities with TPAs.

Appendix 4.3 ranks watersheds by the total area of the watershed that has been designated as an upland ABS. This data will help communities evaluate the importance of their watershed(s) for sustaining biodiversity. The spreadsheet also indicates whether a terrestrial protected area (TPA) has been established and if so, its size, and whether a marine protected area has been established adjacent to the watershed. Connectivity between habitats is important for sustaining biodiversity and MPAs that are adjacent to terrestrial protected areas and mangroves are especially effective. Connectivity between terrestrial habitats, terrestrial protected areas, mangroves and marine protected areas can be determined from Map 6.

Yap State Criteria for Terrestrial Protected Areas (Appendix 5), designates mangroves as keystone areas of biodiversity significance. Mangroves are important for both protection of the land from storm surges and also for their contributions to marine productivity. Mangroves are also important for sequestering carbon and research done on Yap. Donato *et al.* (2011, 2012) indicate that while they comprise about 12% of Yap's area, mangrove forests sequester about 34% of the carbon removed from the atmosphere by Yap's vegetation. Mangroves form a band of varying thickness around much of Yap's coast. Large contiguous areas of mangrove are especially important. The four largest mangroves on Yap were chosen by visual inspection of Map 6, and their approximate boundaries demarcated to determine approximate size. Table 3 lists the 4 largest mangroves on Yap and indicates the watersheds adjacent to these mangroves. Mangroves require some fresh water so the connectivity between upland watersheds and mangroves is important.

The use of the geodatabase is further developed in section 5 that discusses watershed stewardship planning.

2. Assessing indigenous practices relating to watersheds along with scientific literature

A survey of literature relevant to this project was carried out concurrently with field studies of Yapese practices related to watersheds. Given internet limitations on Yap, a U.S.- based college student was employed to do a search of scientific literature relevant to Yap's watershed project. This and other literature that was used in the project is cited in the reference section of this report. Basics concepts are available in The Fundamentals of Physical Geography (http://www.physicalgeography.net/fundamentals/contents.html) and watershed practices are discussed in: Gray & Sotir (1996), Easter, Hufschmidt and NcCauley (1985), McKean and Baisyet (1994), Hamilton and King (1983), Ziemer, O'Loughlin and Hamilton (1990), and Horsley Witten Group (2014).

As described in the methods secion, between August 6 & September 2, 2014, Ms Bernadette (Bernie) Mininug of Yap conducted a total of 176 interviews with 115 people, from 94 of the 119 villages reported in the Yap State census of 2012. Most of the interviewees were women (90/104 for taro patches (*muquot*); and 66/72 for *meliy* gardens. Of the 115 people interviewed, 61 were interviewed about both *muquot* and *meliy,* 11 about *meliy* only and 43 about *muquot* only. The interviewees were chosen based on their reputation for being knowledgeable on these subjects. The topics of the interviews were focused on land management practices that involve water management.

Yap's watersheds are traditionally managed from ridge to reef as shown in Appendix 2, Diagram 17. Interviews served to confirm this diagram of land use in general. Most land management is focused on food production. Major food production systems on Yap consist of "*meliy*" shifting gardens, "*muquot*" taro patch culture, and agroforests (Falanruw 1994). Interviews are reported in terms of practices in intermittent *meliy* gardens and taro patch management below.

2.1. Traditional practices in *Meliy* gardens

In the past, trees were burnt to make *meliy* only for a limited number of special occasions such as an upcoming '*lieu*' presentation in honor of a deceased person, as it was felt that killing trees reduces the '*yungol*' fertility of the soil. Today it is the norm for women to make *meliy* whenever the dryer season creates conditions conducive to burning. The main crop of these intermittent shifting gardens are *Dioscorea spp.* yams, large tubers produced at the base of vines that climb upward onto trees or trellises. Yams require well drained soil, and with a few exceptions it is necessary to manage water and moisture in gardens via ditched beds and raised mounds, "*donguch*". In the more friable soils of Numagil, and Gagil, however, at least in the past, gardening, referred to as "*ma arrow*" and "*tolmol*" and involved growing yams without raised (ditched) beds or *donguch*.

Donguch mounds are generally made in the following traditional zones: '*dep e ted/ tiyid*' (hibiscus secondary forest); *lan e loway* (valley); ' *m'marich lan e lull'* (riparian areas near streams); '*lan e arrow/ arrow'* (just outside of villages in agroforest and secondary vegetation), and '*lane binaw'* (village settlement areas). They were not generally developed on hilltops *('peb gul e borey*', or in savannas (*dak'en e ted / tiyid'*) as they are too dry and windy and there is no material for *do'* mulch to enrich the soil; or '*fithik e niiw qu lan e laey* (coastline- coconut agroforest) or '*charan e malill'* (coastline near mangroves).

It is not known where the practice of making '*donguch*' came from. Types of '*donguch*' include:
1) "*donguch*" which involve the construction of a big mound with about 4 layers of soil added.
2) "*kunuy butaan*" are lower mounds where soil is just gathered into a mound. Both of these methods include the addition of lots of *do'* mulch and it is felt that some special plants like *gachug* (*Codiaeum variegatum), mangeluag* (*Morinda citrifolia*) are especially beneficial.

Leaves of wild and endemic *Pandanus*, '*choi and 'Tha*' may be piled on top of mulch, at least partly because the stiff spiny leaves help to keep chickens from scratching up the mulch. The making of *"loew*" involves the preparation of a hole and then building a mound on top of it. This is a new method perhaps introduced from Pohnpei.

Trellises for yam vines include '*wangrach*' of '*pu'* (small bamboo) which may simply be leaned against a tree, or combined with '*chang'*, a central post made of '*mor*' (big bamboo) or tree logs pounded in the ground. Men used to be the ones to construct the *chang* as this was heavy work. Most of the management that follows is done by women. A great many varieties of yams exist on Yap. For most, especially those more recently introduced, cuttings of harvested yams are planted in the prepared mounds. In some cases however, aerial tubers known to agriculturists as 'bulbils' are planted. Some interviewees indicated that yam bulbils (aerial tubers) produced more problem free yams, and that it is possible to get big yams from these small bulbils. Interviewees indicated that the savanna *teid* was used to grow *guchol* turmeric and *chab chab* arrowroot in the past, and then later sweet potatoes. The seasons for planting sweet potatoes differs in different areas of Yap, apparently as an adaptation to local conditions and needs.

2.2 Landscape management

Ditched and raised garden beds are formed by digging trenches around a rectangular gardening area and depositing the soil onto the garden bed, often in chunks of sod with the root portion on top ('turf loaming'). The ditches serve to drain the gardens. The presence of ditched beds is pervasive throughout Yap (type G.ca on Map 6), and can be seen in aerial photographs of savanna areas where the ditched beds are not obscured by trees. It appears that the development of ditched beds both drains garden beds and also incorporates a number of methods to manage water flow while reducing erosion.

Within a garden, water flow was managed by systems of drainage ditches systems called "*woan', l'lra,* or *maeb"* (note "*woan*" refers to a small stream). Soil from the ditches was placed on garden beds so as to form raised ditched beds for growing crops. When bananas were grown on ditched beds, they were heavily mulched, with soil added from time to time. This soil was taken from holes dug into the ditches intermittently so as to reduce the force of flowing water where needed. Bigger holes were developed between gardens to reduce the force of water flow. They are called *'malibqoch', 'wanum'* or *talra'*. When bigger they may be used for small taro patches for *lak'* or *mal* taro. Stepped ditches may be developed in longer drainage ditches, such as those along paths. The soil removed from these ditches and holes is used to construct *donguch* or paths. Boulders may also be placed on the ground surface between gardens to reduce water velocity and bank erosion, and plants with fibrous roots were planted along streams to hold the soil.

Streams were not straightened, but allowed to curve back and forth so as to reduce the force of water. However, once established they were kept clear of debris so that the stream wouldn't wander or run into a taro patch as this would disrupt their use as paths for people and also freshwater eels ("*wo an e gafiy*"). When streams were kept clear of debris, silt was removed and they developed a base of rocks and pebbles that makes it easier to walk through a stream than along the muddy sides. Stream banks were protected with rocks – as was done in the projects at Okau, Atelieu and Riken. Where ditches run into streams, a hole called '*yibuw*'' was dug in order to reduce the force of the flowing water. (There used to be one at the junction in the river at Okau.) This hole was kept clear of debris ('*bungyibuw*)'.

Lak' taro[3] was formerly grown in ditched beds and the tubers of *lak'* grown in this way was especially yellow and tasty. In taro patches *lak*' taro is subject to a problem called '*ngal*'[4] but it is observed that there are less *ngal* problems in drier taro patches. Many trees are used for mulching gardens. The tree Hibiscus, "*gal*'" is considered to be especially good. Some people say that '*riye'* (Cerbera) and mango leaves should not be used for mulch because they are sappy.

2.3. Traditional practices in taro patches

There are 5 main kinds of taro grown in Yap: *lak'* or giant swamp taro, *Cyrtosperma merkusii* (formerly *C. chamissonis*) generally referred to as "taro" on Yap; *mal* or true taro, *Colocasia esculenta*; "*laiy*", *Xanthosoma sagittifolium* is an introduced taro sometimes called "Honolulu" though it actually originated in the Americas; and *Alocasia macorrhiza* is a hardy taro grown more in the outer islands than on mainland Yap.

2.3.1. Kinds of taro patches

A variety of taro patches are found throughout Yap from ditched bed areas in the savanna to secondary forest on slopes in valleys, near streams, and especially in tree garden agroforest village areas. They are generally absent from hill tops and coastal areas where there are coconut groves or mangroves. While the general term for taro patches is "*muquot*", there are a number of named categories based on where they are, how they were formed and how they are used.

Taro patches found in the savanna and inland secondary forest are generally "*talraq*", small taro patches created by enlarging ditches between garden beds. Most *muquot* taro patches occur in valleys, near streams, in agroforest and in villages. Here, those that are formed when soil is removed from holes to create raised gardens are called "Milboquch" or "Wanuum" (in different parts of Yap). Muqut ni gaa' "or "muqut ko Pumoon" are large taro patches formed in areas that

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[3] Technically the term "taro", derived from Polynesian names for *Colocasia* applies to *Colocasia* taro. On Yap however the term "taro" is generally applied to *Cyrtosperma* taro while the Yapese term "*mal*" is used for *Colocasia* taro.

[4] "*Ngal*", the Yapese term for termites, is used to describe an affliction of *Cyrtosperma* taro. The problem is thought to be due to a combination of a nematode and bacteria that produce ragged holes that make the corm look like it was eaten by termites.

are naturally low. Some of these areas were formerly filled with *Hibscus tiliaceous,* the tree hibiscus that often grows in freshwater swampy areas. Traditionally they were for men of the village though sections might be cared for by individuals. A small portion of a larger taro patch, or a small individual taro patch bordering other taro patches is referred to as a "goep". Traditionally "*muqut ko Pumoon*" were tended by men or older women for men, and young women did not work in these taro patches. Some taro patches were for families and they were traditionally tended by mature women. Today even younger women work in these taro patches.

2.3.2. Moisture and water management in taro patches

Both *Colocasia* and *Cyrtosperma* taro can be grown in either garden areas or taro patches. Some *Colocasia* is grown in moist areas of gardens, and in the past *Cyrtosperma* was sometimes grown in ditched bed garden areas. It is most productive however, to grow these taros in taro patches where there is constant moisture. During droughts, soil is mounded around taro plants to prevent them from drying out, and to prevent the suckers from detaching prematurely, and ditches may be dug to direct water to the taro plants. Some tree roots, such as those of *Hibiscus tiliaceous, ramlieu, watol* and betel nut invade taro patch and tap the water. These trees are cut back to avoid competition of their roots for water and nutrients. Some may be left however to provide shade to "encourage" taro to grow tall.

Traditionally many methods were used to manage water flow in relation to taro patches. Stream banks were lined with stone to prevent them from invading taro patches or failing to remove excess water away from taro patches. Water flow was managed by banks called "*n'ey"*, or by varying the width of a ditch or stream. Sometimes ditches were dug into slopes above taro patches to drain away excess water and allow it to gently seep through the soil into taro patches. In such cases, the bottom of the ditch was kept somewhat higher than the taro patch so as to maintain an appropriate water level within the taro patch. It was also necessary to manage the depth of streams. If drainage ditches or streams became too deep, they would drain too much water from the surrounding area and tend to dry up taro patches. In such cases berms were built to trap soil and small rocks so that the bottom of the stream was raised. Another ingenious method of raising the level of a wide ditch or stream was to plant closely spaced betelnut palms along the stream bank. The roots of the betelnut palms served not only to hold the banks, but they also develop adventitious rootlets that grow out and up into the stream. These fine but strong roots serve to filter out rocks and other debris so that the bottom of the stream bed is raised, thus raising the water table in the area to a level conducive to taro growth. Should the stream become too shallow, the betelnut palms can be cut down.

Most taro patches have an inlet and outlet for water to flow through the taro patch. Some small individually dug taro patches may have only an outlet to drain water after heavy rains. The inlets and outlets, called "*wun*", are managed to ensure appropriate drainage and a gentle flow of water so that the taro patch does not get stagnant or too shallow or too deep. The velocity of water flow in drainage ditches was managed in order to prevent erosion. This was done in a number of ways including the slope of the ditch, the creation of deeper holes within the ditch, and the lining of ditch bottoms with rocks. During periods of drought, the outlet channel of the taro patch might be blocked with soil or with rocks wrapped in the sheath of a betelnut inflorescence ("*wathir*").

If a taro patch area is too deep, a raised bed may be built with materials on the site such as logs, coconut husks, and fern roots and filled with soil. This provides a planting area for taro so that it won't drown in the deep water. Another method used for growing taro in deeper areas involved the weaving of baskets of coconut fronds and then filling them with good soil to form an elevated growing "pot". In some deeper areas, the baskets were elevated and held in places with sticks. Taro is planted in the raised baskets, and when it becomes large, its roots are able to grow through the bottom of the basket and make use of the fresh water and nutrients below. An extreme case of such "taro hydroponics" was floating taro patches developed in a few places with very deep fresh water marshes. In these Yapese taro hydroponic systems, taro was planted in a floating mat of plant roots, and debris (Falanruw 1993).

While this project focused on managing water flow, it was carried out during a period that included a severe drought. The drought followed an intense ENSO "El Nino" event as was the pattern with the especially severe droughts of 1982-83 and 1997-98. The drought of 2015-16 resulted in the driest period from October to March on record as well as more limited rainfall in the months before and after this period. As a result of the drought, many taro patches, especially smaller man-made taro patches such as *milbuquch* dried up. Many taro patch owners harvested taro and took advantage of the dry conditions to recondition their taro patches. Unfortunately the dry conditions killed most of the remaining corms that might be used to replant the taro patches. In the past this planting material might have been obtained from the deeper areas of "*muquot ni ga*". Unfortunately over the years of abundant rainfall associated with a prolonged "La Nina", many of these deeper taro patches have not been tended and have become overgrown by tall *Phragmites karka* reeds that shade out the taro. Thus a lesson to be learned from the drought of 2015-6 is that the old people had a reason for maintaining even the taro patches located in deeper areas.

2.3.3. Management of salt water inundation and intrusion

The development of raised taro beds and 'basket culture' (section 2.3.2.) also serves to place the roots of the taro above saline water so that the taro is not as affected when these taro patches, many of which are coastal, are temporarily exposed to salt water. This method was used in some low sandy areas that had been affected by salt water after Typhoon Sudal but in most cases the taro was killed by subsequent and more prolonged salt water intrusion.

Especially high "king tides" or storm surges can fill coastal taro patches with salt water and kill the taro. After such events taro plants are harvested before they go bad. In gently sloping coastal areas, drainage ditches serve to drain salt water after especially high tides and storm surges and subsequent rains flush out the salt water. After Typhoon Sudal in 2004, many taro patches were renovated by the clearing and repair of drainage systems. Post-typhoon rains flushed out salt water so that taro could be replanted, sometimes growing better than before.

After Typhoon Sudal, one village with limited coastal area suitable for taro rehabilitated a taro patch that was subject to flooding after heavy rains, and also subject to flooding by very high tides. They constructed dikes along the lower part of the taro patch to keep salt water out at high tide. In addition they installed a large pipe with a 45 degree angle through the dike. When the taro patch was affected by heavy rains, the pipe was lowered at low tide to enable the taro patch to drain. At high tide the pipe was raised so that salt water could not flow into the taro patch.

Sometimes, in more level coastal areas, dikes alone cannot prevent salt water intrusion from below as the pressure of a high tide enables salt water to percolate through the porous soil into the taro patch from below. In some coastal taro patches, a deep trench was dug on the landward side of a dike or stone path parallel to the coast. This trench was filled with stones and allowed to fill with fresh water. The pressure of the fresh water then served to prevent salt water intrusion from below.

2.3.4. The use of diversion swales and check dams

More macro management was traditionally applied to taro patches occurring in marshy areas in valleys that empty into mangroves and the sea. Here water flow was diverted at the head of the valley into wide shallow swales that ran along the side slopes of the valley parallel to the taro patch. This prevented water from upslope from rushing into the taro patch and washing out taro plants and eroding away the rich sediments needed to grow taro. At the same time the swales allowed for a gentle percolation of water through the soil into the taro patch so that it remained moist. Roots, often of *Hibiscus tiliaceous* trees prevented the erosion of the soil in the swales. Running cross slope and parallel to the taro patch the swales also provided a convenient walking path for reaching taro patches. As people utilized the path, they also maintained it, cutting away intruding vegetation or shoring up side banks so that they were not eroded away.

Figure 1. The old style swale diverting water above the taro patch lies to the right of the path and is now filled with vegetation. Note that it runs along the valley slope above the taro patch. The new type of water management ditches are made at the edge of the taro patch to the left.

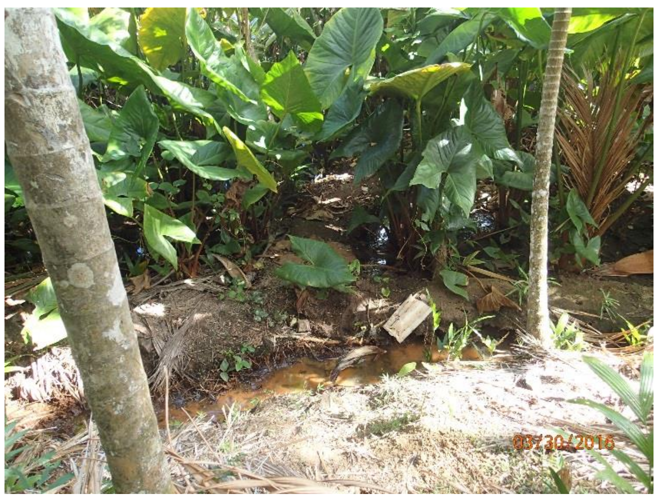


Figure 2. A contemporary water management ditch at edge of taro patch with a soil dike made into the taro patch to prevent water flow from washing away taro plants.

The management of water runoff in swales across valley slopes was complemented by the development of low check dams at the lower end of the taro patch. These low dams served to further slow the flow of water out of the taro patch so that sediment was deposited, leaving a thick layer of nutrient-rich soil for taro. At the same time the dam prevented the flow of salt water into the taro patch. The height of the dam was adjusted so that it allowed excess water to drain from the taro patch after periods of heavy rain, but high enough to prevent the entry of sea water at high tide. From time to time it was adjusted to adapt to conditions such as extra high "king tides".

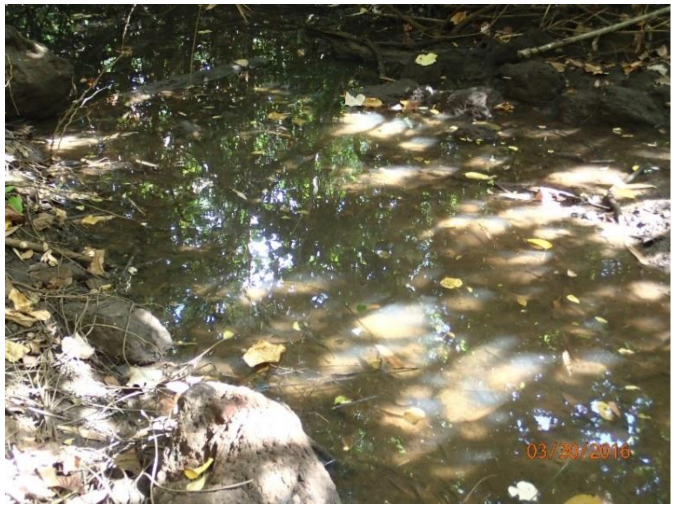


Figure 3. Remnants of an old rock dam at lower end of taro patch.

Few of the diversion swales survived the Japanese administration of Yap and World War II, as Japanese agriculturalists disrupted the system so that the taro patch would fill with soil and silt and could be used to grow Chinese cabbage and other crops for the large population of Japanese occupying Yap prior to WWII. By the end of the Japanese administration of Yap, there were only about half as many Yapese and not enough people power to restore the original system. In its place Yapese women took to managing the water in taro patches with ditches and berms along and within the taro patches. This more “micro” management continues today and only remnants of the former system of diversion swales on valley slopes remain.

The system of check dams at the lower end of taro patches has also fallen into disuse resulting in major problems. Without the dam, silt from the taro patch is eroded away and travels from where it is needed as a growing medium into the marine environment where it becomes a pollutant.

Figure 4. With the demise of the rock dam at the lower end of the taro patch the banks of drainage channels are eroded away allowing salt water to penetrate further inland. Here salt water has moved some 200 ft. upstream in about the last 25 years.

As the soil erodes away, the drainage channels within the taro patch become deeper. As the discharge velocity increases, stream banks are eroded in a process of bank caving. As the sides and bottom of the channel erodes further inland, drainage from the taro patch is increased and some areas are left too dry for the cultivation of taro.

Figure 5. The once moist taro patch in the foreground has been left high and dry as the rate of fresh water drainage increased due to the deepening of the eroded ditch in the background.

Without the presence of the dams to maintain the a pool of fresh water upslope, salt water is able to flow further into the taro patch and to bubble up into the taro patch at high tide. This results in salt water intrusion reported in many places in Yap and especially in the Outer Islands of Yap.

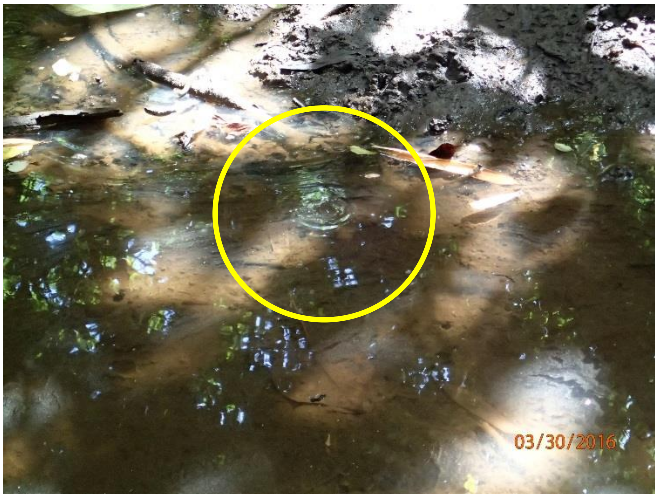


Figure 6. As the tide rises in the absence of a dam to maintain an upslope pool of fresh water pressure, salt water intrudes through the soil and bubbles up.

The problem of progressive bank caving is occurring in many areas on Yap, drying up taro patches and allowing salt water intrusion. Climate change will increase this problem as increased rainfall results in increased erosion and sea level rise results in increased salt water intrusion. In this scenario, the re-application of a traditional technology can be used to extend the life of taro patches both on Yap and in other areas of the Pacific with coastal taro culture.

2.4. Mapping and assessment of taro patches and gardens in relation to elevation above sea level and salinization

Taro culture and shifting gardens are very important in Yap, but we have not been able to map their incidence using aerial and satellite imagery as they are generally obscured by tree canopy. We thus addressed the need for data on taro patches and shifting gardens through the field surveys described above. Along with information on management of gardens and taro patches, interviewees were asked to locate their taro patches and gardens on a USGS map of Yap. The hand drawn maps of taro patches and gardens were then photographed and incorporated into our GIS system where they were adjusted to fit GIS maps. They were then made translucent so that the locations of taro patches and gardens could be seen in relation to the GIS maps, and the sites were transferred onto the GIS map. The data could then be related to elevation zones above sea level by using the DEM layer of Yap's GIS database. The ideal of combining traditional and modern knowledge is often cited as an ideal but seldom accomplished. In this exercise we were able to meld traditional knowledge with modern GIS technology!

2.4.1. Taro patches, salinization and elevation above sea level

For taro patches, interviewees were asked to identify any that have been affected by salt water. Four size classes of taro patch were mapped and color coded to indicate salinization, or, in the case of some large taro patches, partial salinization. This resulted in the mapping of some 2,707 taro patches and 1,954 gardens throughout Yap. We estimate that this survey has captured at leat 95% of the moquot ni ga taro patches, about 80% of the smaller classes of taro patches and recent gardens on Yap. Because the maps were based on interviews the locations indicated on the map may not be precise and bears field verification using GPS technology. Likewise the degree of salinization of taro patches should be field verified with salinometers. Nonetheless these anecdotal data provide very important information that has never before been available on the incidence of these food production systems. This information is vital to evaluating food capacity and the vulnerability of taro patches to salinization resulting from climate change and sea level rise.

Of the 2,707 taro patches that were mapped, 80 lie in the 1-2 m elevation zone, 516 are located between 3-5 m of sea level, and the remaining 2,111 were above 6 m of sea level. The area of taro patches in these zones is also important as larger taro patches tend to be located lower in the watershed. The area of taro patches was estimated by applying buffers to the point data on small, medium and large taro patches to indicate approximate area, as discussed in the methods section. Table 2 provides data on the size class, and elevation zone of the 2707 taro patches mapped.

This preliminary mapping of taro patches indicated that many taro patches lying within 2 meters of sea level have been affected by sea water. This was expected. What was not expected is that some taro patches affected by salt water appeared to be located up to 5 m above sea level! In addition, there were taro patches lying within 2 m of sea level that were not reported to be affected by salt water.

Type	# sites	Avg Area (m2)	Total Area (m2)	Area 1-2m* (m2)	Area 3-5m (m2)	Total Area (m2)
Talra	499	78	38,993	1,542	3350	34101
Mulbuoch	1187	703	834,421	15,424	121,281	697,716
Muqut	882	6,655	5,870,076	286,986	1,551,155	4,031,935
Muqut ni ga	139	18,207	2,530,747	15,677	894,362	1,620,708

Table 2. Number and area of 4 classes of mapped taro patches within 2 m and 5 m of sea level

The anecdotal information on taro patches was complemented by a GIS analysis of areas most suitable for taro production based on slope and soil type (Map 8). This exercise indicated that some 68% of the area suitable for taro production lies within 5 m of sea level. Combined with the finding that many taro patches occurring in this zone are already affected by salt water, this analysis raises concerns for Yap's food security.

2.5. Shifting *meliy* gardens

This project resulted in the mapping of 1,959 sites of where shifting *meliy* gardens are made. Seven of these sites were located in the 1-2 m zone, 56 in the 3-5 m zone and 1,896 in the 6-177 m zone. Yap's system of swidden gardens is important and popular because it has the potential of producing large yields in proportion to work input because these gardens are in effect "subsidized" by forests. They require the sacrificing of trees to make use of the soil made fertile and friable by the trees which are then used as trellises for crops with climbing vines, the most important of which are *Disocorea* yams. After about 1-3 years, the gardens are left to go fallow, and if conditions are good and the area is not bulldozed or affected by wildfires or invasive species, a secondary forest regrows, and may, if not further disturbed, develop into more mature forest. More detailed information on Yap's shifting gardens is available in Falanruw (1994), and Falanruw & Ruegorong (2010, 2015). The significance of shifting cultivation in Southeast Asia and the Pacific is re-examined in two books (Cairns 2010, 2015).

Shifting *meliy* gardens are generally made in areas of secondary vegetation as they are closer to home. If access to better developed forests is available however, women are keen to make use of these areas for gardening. These areas promise higher yields for less labor, because there is less of a weed problem and the soil is more fertile and friable. Roads and vehicles provide more easy access to Yaps forests. Where roads have been built into forested areas, the native forests have been converted to *meliy* gardens and then weedy secondary vegetation. As sea level rise affects lower-lying taro patches, there will be a need to move agricultural activities upland. With increased road access, Yap's limited area of better developed forest is likely to come under increased pressure for conversion of upland forests to food production. Deliberate strategies for maintaining biodiversity while achieving food security are urgently needed.

3. Developing Public Awareness of Watersheds

Public awareness of watersheds was developed through: Public displays and dissemination of information to leaders and the general community, community consultations, and presentation of GIS maps and watershed stewardship discussions with four selected communities.

3.1 Public displays and dissemination of information

Prior to the completion of the Yap Watershed proposal, discussions were held with relevant individuals and groups. Initial groups included Yap's Council of Chiefs in order to obtain their endorsement of the project, and the Yap Women's Association, as women are the main stewards of land resources on Yap.

Public displays and dissemination of information on watersheds and the Yap watershed project included events such as the Yap Day observations of 2014, 2015 and 2016, when the whole island comes together to celebrate Yapese culture, Earth Day 2014, 2015 and 2016; The South

Pacific Community/ EU regional meeting of 9 Pacific countries, on Sustainable Climate Change Adaptation held on Yap in 1915; Yap High School, Yap Catholic High School, and College of Micronesia Days. Communities and groups were invited to request further information and presentations and additional presentations and consultations followed. Additional presentations on the project will be given at the Yap Youth Conference in June 2016, and in the National FSM Women's Conference in October 2016.

3.2 Community consultations

In addition to the displays and dissemination of information, the project included a program to visit every village on Yap to discuss watersheds as well as to map the location of areas important for food production. This resulted in consultations with 115 people from 94 villages. Results of interviews are incorporated into Section 2.

More in-depth discussions were held with four communities selected as sites for watershed projects. Communities were selected based on community interest and readiness, need, the achievability of projects within the available budget and time frame of the grant as well as the applicability of the projects in other parts of Yap. Given our budget and time limitations, smaller villages and projects were chosen as it was anticipated that larger community projects would eventually be possible utilizing the watershed geodatabase produced by through this project to develop proposals for support from a variety of sources. There are already two other communities interested in utilizing the watershed database for projects. Section 5 describes how the watershed geodatabase could be used by these communities.

4. Implementation of Projects in Selected Watersheds

The four sites chosen for projects were Atelieu, Okau, Riken and Gargey. The first three villages were concerned about stream bank stabilization to protect taro patches from erosion, while the fourth village wanted to restore stream conditions for their specialty fishery. With climate change predictions calling for increased rainfall and storms in the years ahead, the management of streams is a timely project that relates to food security and biodiversity protection with relevance throughout Yap.

4.1. Atelieu and Okau projects

Atelieu and Okau villages are located on the steeper western side of Yap and have limited coastal flatland. Their coastal taro patches are very vulnerable to sea level rise and storm surge. As an adaptation to climate change, villagers want to renovate taro patches occurring more upland. Over generations streams were managed so that they provide the right amount of gently flowing water to taro patches without washing away the rich silts needed to grow taro. These silts were carefully managed to grow Yap's main taro, *Cyrtosperma merkusii*, 'lak', a taro that can be integrated with agroforests to maximize production throughout the year. Narrow paths generally run along the sides of streams, serving as both levees and foot paths and are maintained along with the streams. This leaves room for human habitation and agroforest in the limited area of more level village land.

Modern changes and the advent of wage employment for both men and women, have reduced the labor force to maintain the upland portion of streams. Until now this has not been a big problem as there are plenty of coastal taro patches. Unfortunately sea level rise and more frequent storm surges are now affecting coastal taro patches and threatening food security and it will be necessary to begin using upland taro patches. Most of these upland taro patches have, however, been damaged as a result of erosion of stream banks during heavy rains. This has resulted in the loss of the rich silt from taro patches used to produce one of Yap's most important staple foods.

The work in both villages involved clearing fallen logs and invasive vegetation, relocating boulders, restoring stream and taro patch banks by reconstructing stone retaining walls and planting agroforest trees and shrubs along the river banks to help hold the banks in place. Okau village committed to restoring 1,420 feet of their stream and planting 150 trees and shrubs and Atelieu committed to restoring 1,500 feet of their stream and planting 150 trees and shrubs. Both communities exceeded their commitments. The streams are located in forested areas that can only be reached on foot, and all work was done with hand tools. The project is already resulting in the protection of taro patches which are again collecting the rich silts needed to grow taro and individual taro patch owners are now beginning to renovate their upland taro patches to replace those damaged by rising sea level and storm surges.

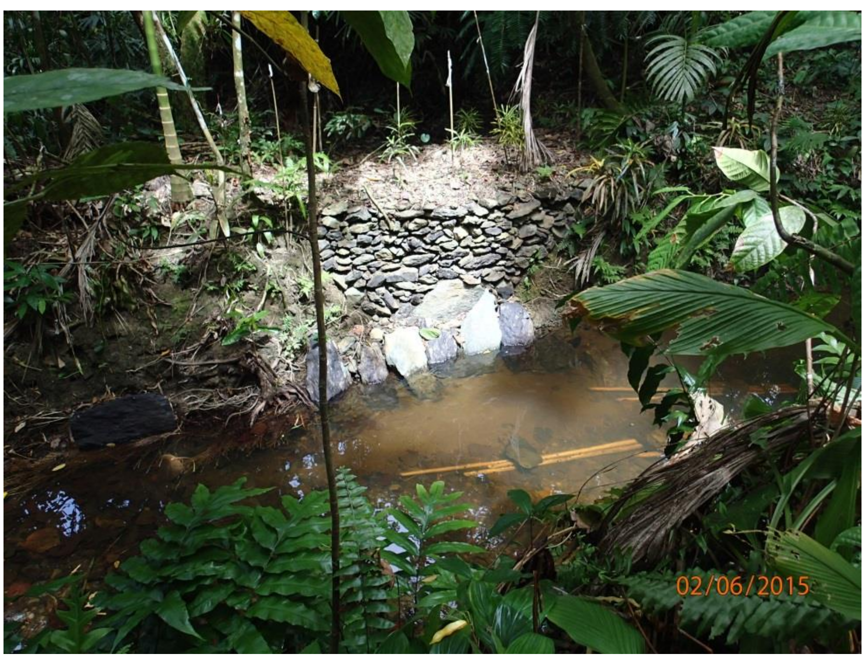


Figure 7. Larger rocks are used where the pressure of flowing water is greatest. Shrubs and trees are then planted along the stabilized stream to help hold the soil.

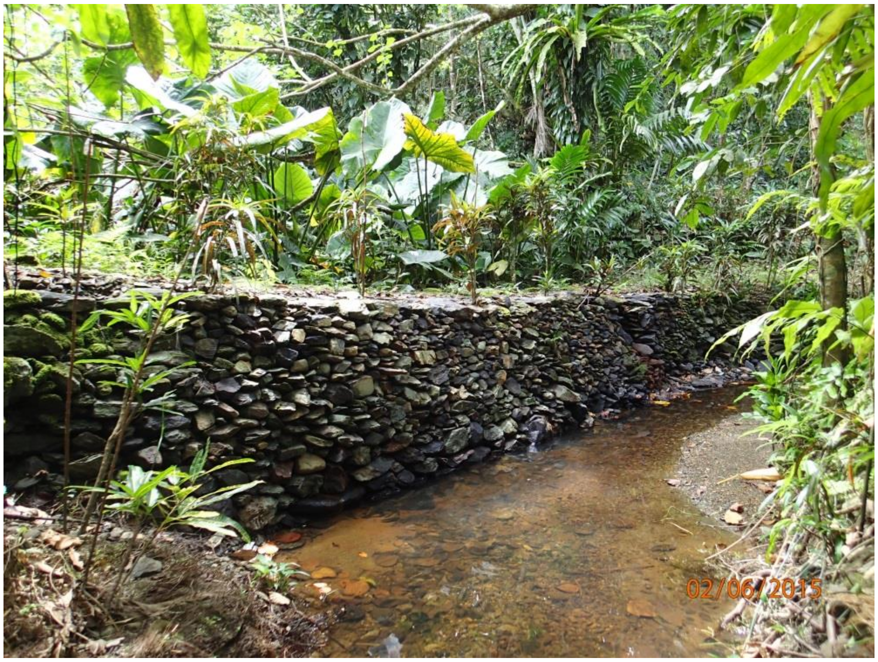


Figure 8. Hand built rock wall prevents stream from washing away rich silts needed to grow taro in taro patch in background. Upland taro patches are now being renovated to replace lower lying coastal taro patches that have been affected by salt water intrusion.

The project was not without challenges. In some places large tree roots have grown into the stream and diverted water flow. In other places large boulders have fallen into the stream and cannot be removed with local manpower alone.

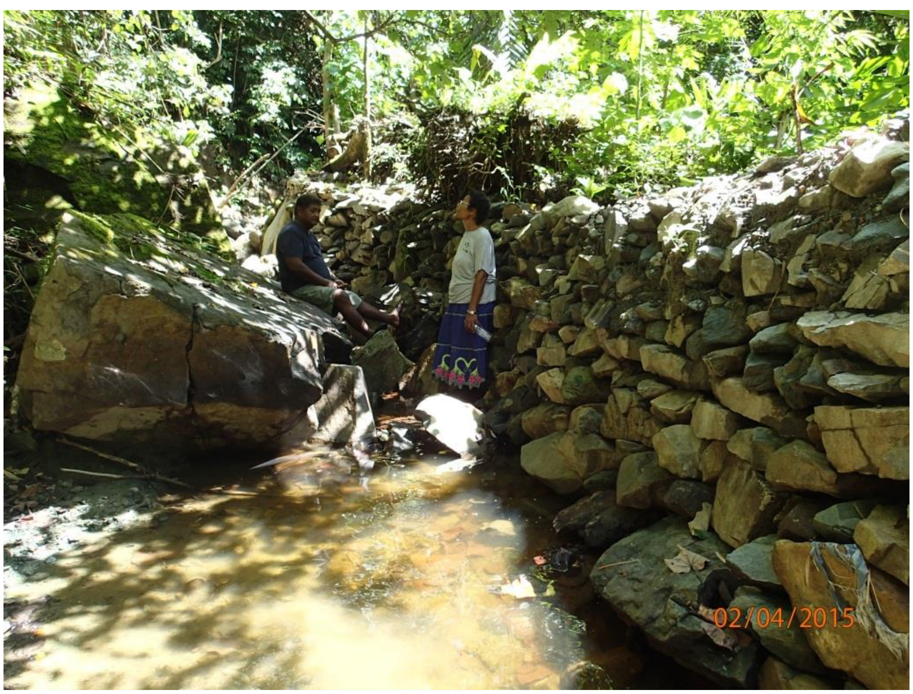


Figure 9. Large boulders have fallen into the stream in places where it is not possible to remove them with heavy equipment.

Discussion, Atelieu and Okau projects

Some of the repaired stream banks have been damaged as a result of heavy rains associated with a record number of typhoons passing near Yap in the last year. Climate change reports predict an increase in storms and rainfall for Yap in the future. It will not be feasible for villagers to continue to repair and maintain stream banks by traditional handiwork with stones alone. The staff working with the Yap watershed project has considered practices available for stabilizing stream banks. Most stream bank stabilization projects in larger countries involve more land and gentle slopes than are available in these villages, and the use of heavy equipment to move rocks, or the use of cement. These methods cannot be used without sacrificing the taro patches, home sites, and agroforests that the project is trying to protect. Cement could be used but is difficult to transport up into the forest, and if a cemented rock wall is broken, it is not easily repaired. In addition, cement walls would remove habitat for stream life such as freshwater shrimp. The Yap watershed team thus consulted literature and a number of experts and determined that the best practice in this case would be the reinforcement of the rock walls with heavy mesh. Wire mesh has been used in several coastal areas of Yap with good results. Heavy mesh will hold rock walls in place and still allow percolation as well as accommodate habitat for stream life. Eventually tree roots will secure the mesh and strengthen the embankments. Technical assistance to obtain and install wire or suitable geotextile mesh is needed for future projects. While stabilizing stream banks is important, it is also important that the level of the stream bed is not lowered at its mouth as this could result increased drainage and lowering the water table needed to maintain taro patches as was discussed in section III.2.3.

4.2 Riken project

Figure 10. The Riken project stabilized banks of a stream that connects a series of habitats from upland forest to mangroves. Here the stream passes through an agroforest with taro patches.

The community of Riken had worked on stream bank stabilization with a grant from Australia, some years earlier and needed to continue the project further upland in order to protect a large taro patch and a number of smaller ones along the stream. Erosion had occurred during periods of heavy rain when the blocked stream overflowed its banks. The project is especially important as adjacent villages, where more people live, are located on a narrow strip of coast between the sea and steep slopes (see map 15 in Appendix 2). There is limited habitat for growing taro and the area is quite vulnerable to sea level rise and especially storm surges. The project site is less vulnerable to sea level rise and storm surge and is important for food security. In the area of the project, the stream runs through a series of natural communities including a forested area, an agroforest area, a fresh water *Barringtonia racemosa* swamp, and *Nypa* palms into a mangrove bordering the lagoon. With no sources of industrial pollution, the stream and riverine area provides habitat for native fauna including eels, coconut crabs, native shrimp and a probable new species of cricket that was found along a similar wild stream (Falanruw, Ruegorong & Cruce 2010). The stream provides connectivity between the upper watershed that includes a terrestrial area of biodiversity significance (ABS) and the portion of the stream downslope which empties into a marine ABS with an established MPA.

The work was initiated on August 9, 2014, and was completed by January 15th, 2015. The community exceeded their objective of restoring 800 feet of the stream by restoring an additional 350 feet and clearing a path along the sides of the stream. At a number of areas where bends in the river increased the force of running water, streambanks were stabilized with stone and log retaining walls. One retaining wall was built with a combination of stones and logs as there were not many boulders available. Over 110 agroforest shrubs and trees were planted to further stabilize the stream banks.

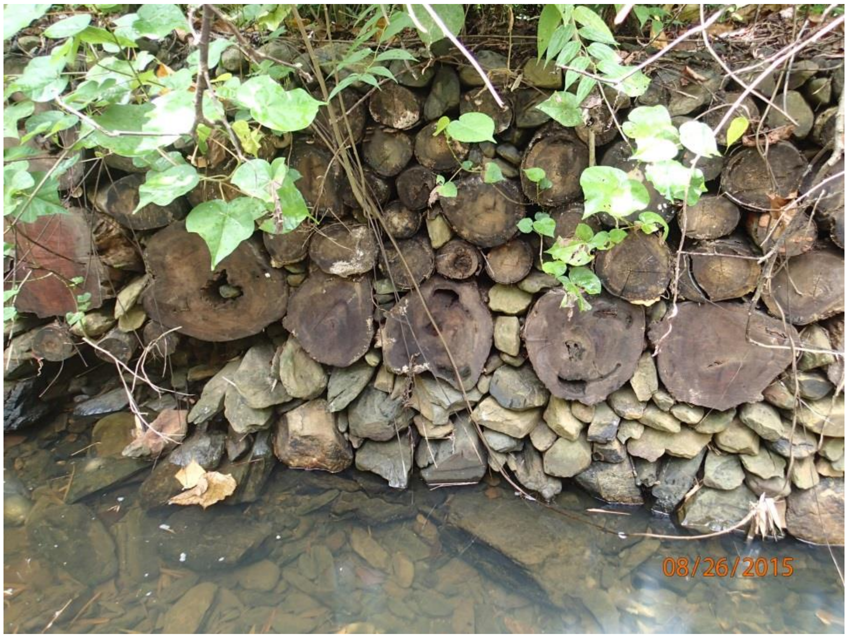


Figure 11. Retaining wall built of rocks and short logs as there were not many large rocks on the site.

Another retaining wall was built with small logs piled parallel to the river and held in place by hibiscus posts. The hibiscus posts have since sprouted and are growing to provide a living support for the riverbank.

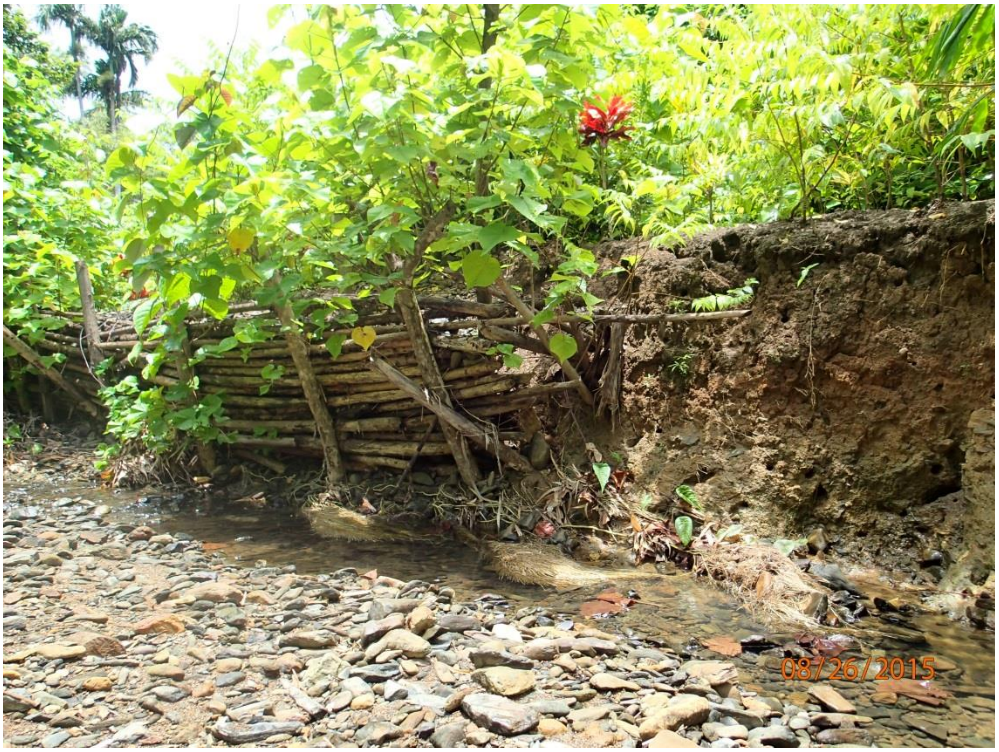


Figure 12. Retaining wall built with small logs and held in place by *Hibiscus* stakes that have since sprouted to form living posts.

With the clearance of debris from the stream and the stabilization of stream banks, people were already beginning to renovate taro patches along the stream. The figure below shows a taro patch area prior to restoration activities. Here overflow from the formerly blocked river would enter the taro patch area during heavy rains, and then carry away the rich silt needed to grow taro when the waters receded.

Figure 13. Here the stream overflowed its banks and scoured out the rich silt needed for taro patches in the background to thrive.

In another part of the site project staff constructed a modest stone check dam during inspection visits to the site. This simple wall slowed water flow so that it dropped its sediment load on the upper side of the wall. Already the taro patch is doing better.

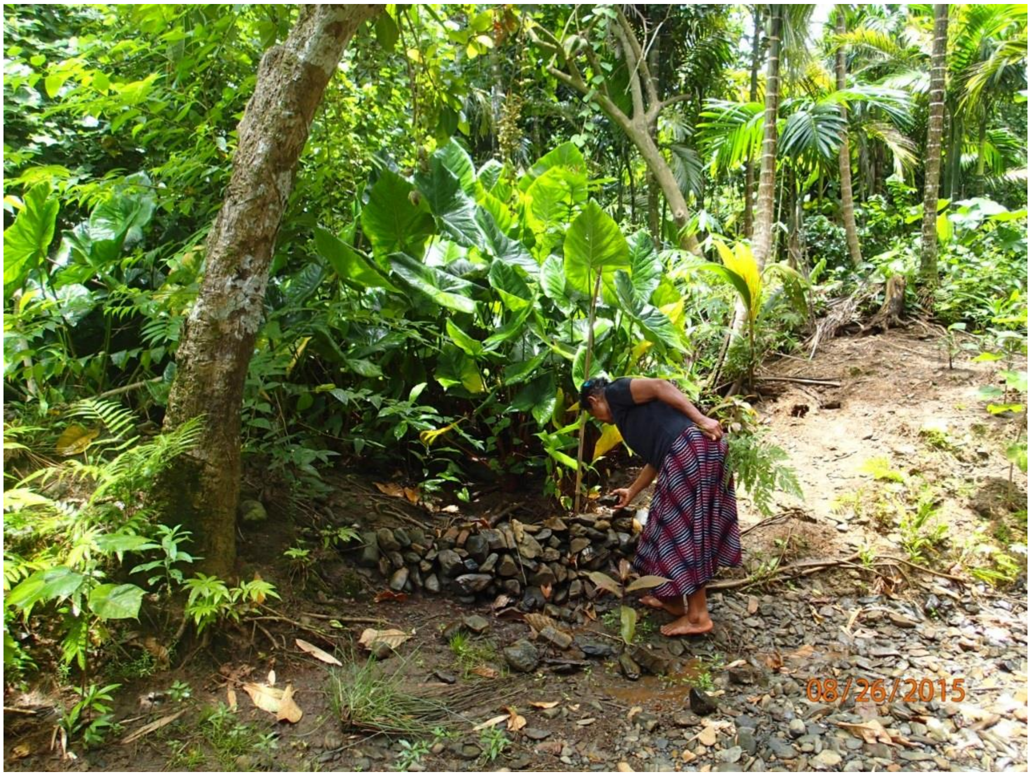


Figure 14. Bernie Mininug adding rocks to a modest retaining wall that prevents the erosion of rich mud from the taro patch which is already starting to thrive. This is an example of Yapese “nature-integrated technology” where people work along with natural processes.

Discussion, Rikin project

One lesson learned in this project is that removing too many trees along the stream admits more sunlight and encourages the growth of algae and weedy herbaceous species that tend to clog the stream. This was pointed out after inspection of the first phase of the project and fewer trees were removed on the next phase of the project

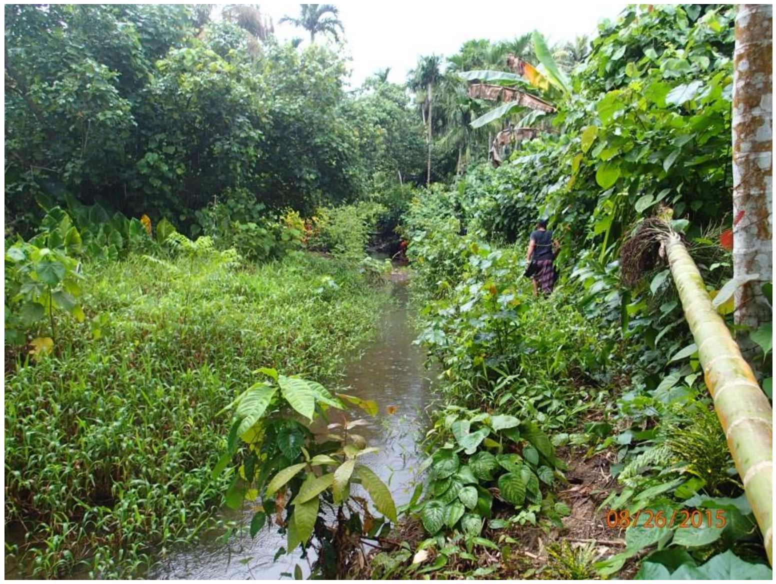


Figure 15. Portion of the project where many trees were removed resulting in rampant growth of weedy herbaceous plants that clog the stream.

As with the other projects, parts of the stream banks were damaged by heavy water flow following periods of intense rainfall associated with passing storms and typhoons.

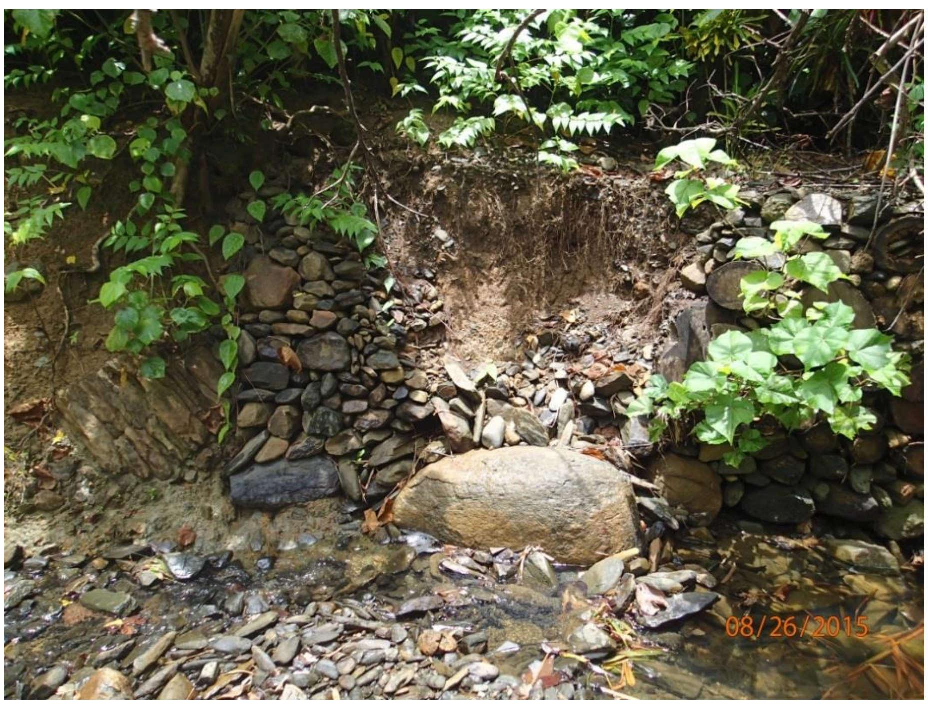


Figure 16. Rock walls built to protect stream bank at a curve where water flow has more force. A portion of the wall has been damaged by heavy water flow following intense rains associated with passing typhoons.

In the past when this area was densely populated, the stream banks would have been repaired as part of the process of tending the taro patch. Today people must juggle this type of work with salaried jobs. In addition, climate change reports predict increased rainfall and increased incidence and intensity of storms, so enhanced methods of stabilizing stream banks are needed if residents are to retain food security in today's world.

4.3. Gargey project

Figure 17. View of upper part of stream that has been cleared of debris. Part of the streambank, at a curve where Mona Yagatinag is sitting has been protected with rocks

Each of Yap's villages has its specialties. The village of Gargey is known for its *milme'* fish and large mangrove clams. The fish is collected when it migrates from the lagoon up a main stream and mangrove clams are collected in the mudflats around the stream and mangroves. The streambed became shallower after a large cement bridge-type culvert was replaced with smaller culverts during a road renovation project. The culvert was installed where the road passes over the stream. Water flow in the upper portion of the stream has increased after two streams were merged during previous roadwork. One of the small streams was not indicated on the USGS map and had not been accommodated in the engineering plan for the road. The merging of the two streams has resulted in considerable stream fluctuation during heavy rainfall events and resulting runoff carrying with it rocks, soil and debris. This resulted in sediment deposition and damage to the fisheries. The community felt that clearing debris blocking the stream might open the waterway from the sea to the mangroves and help restore the fisheries. It might be noted that the intent of this project is the reverse of that used for taro patches where check dams are used to prevent salt water intrusion. Here the community wanted to deepen the stream so that salt water and *milme'* fish would return upstream as before.

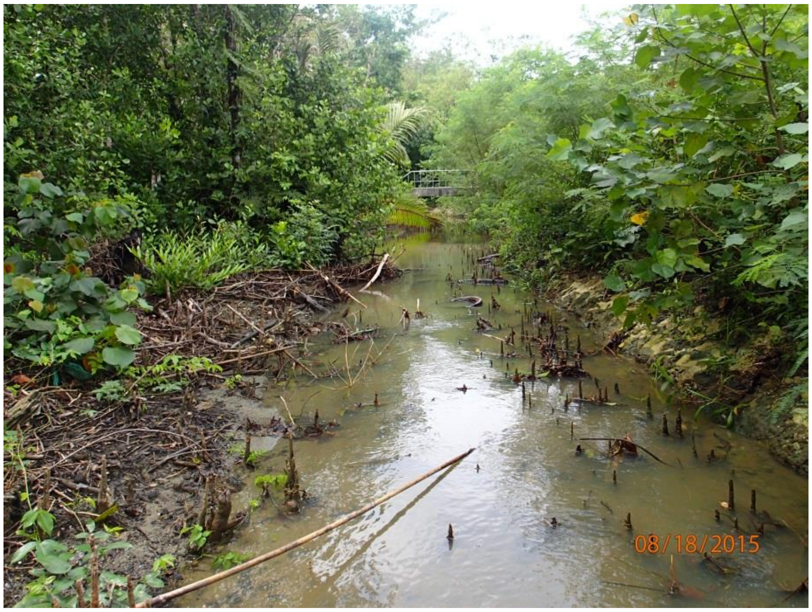
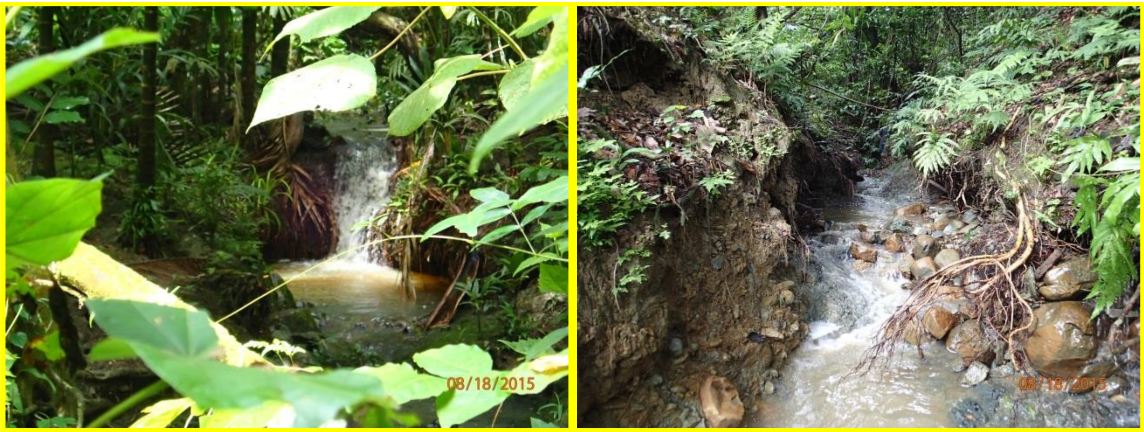


Figure 18. The *milme* fish were formerly netted in considerable numbers in the stream in the proximity of the bridge in the background. Road construction involving the installation of a smaller culvert has resulted in filling in the stream and the growth of mangrove roots into the stream bed.



Figures 19. The upper portion of the stream becomes steep and rainwater runoff can erode stream banks during heavy rainfall events.

The community restored over 600 feet of the stream, clearing away debris, boulders, fallen logs and invasive and weedy vegetation. The banks of the stream were stabilized with rocks and boulders and fibrous rooted shrubs and trees were planted along the bank of the stream. A large amount of rubble that had built up at either end of the culvert was also removed.

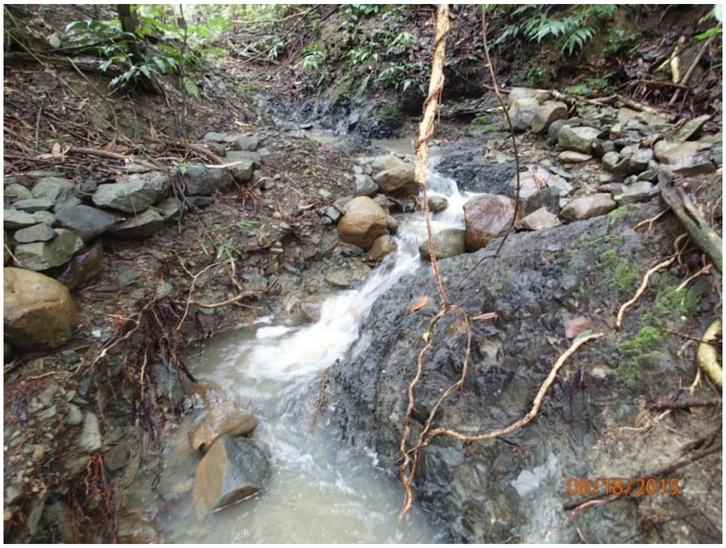


Figure 20. Rockwork was installed to withstand increased water force at curves.

Unfortunately, clearing debris from the stream is only part of the problem. The culverts installed in the road lie at a slight angle to the stream and are smaller than those previously in place. As a result, heavy water flow carrying soil, rocks and debris slows down and drops its load at either side of the culvert which is too small to accommodate the volume of the stream. This results in the buildup of a bank of soil and debris on either side of the culvert. The stream on the upper side of the culvert was cleared of debris, but the small culvert is likely to become clogged again.

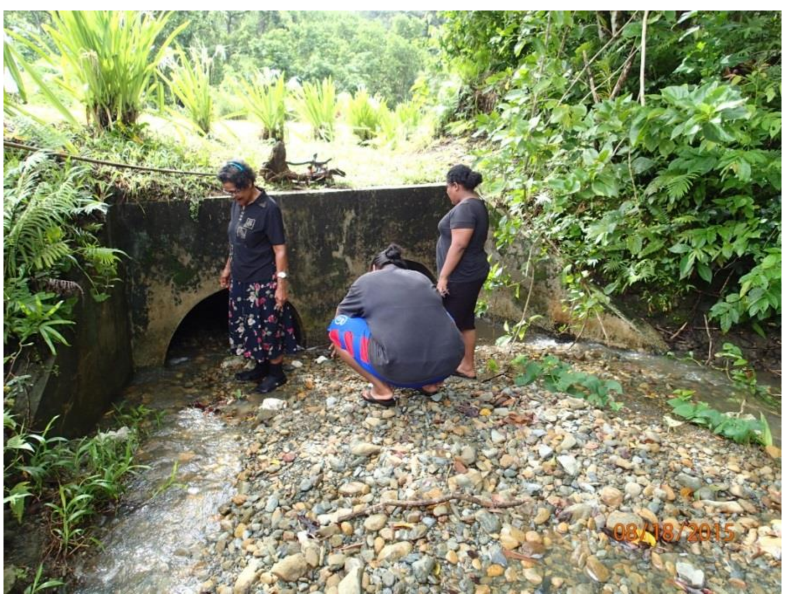


Figure 21. While the community cleared debris from the stream, the culvert appears to be too small to accommodate the fluctuating volume of water flow from streams and is likely to become clogged again.

4.4 Lessons learned from projects

The 4 projects reported here and observations of other projects provide a number of lessons:

- Traditional technologies show a deep understanding of managing streams.
- The current generation has an interest in renovating the traditional rockwork used to stabilize streams. However, this work was damaged as a result of a period of especially heavy rainfall. Given a reduced labor force and other demands on people's time, it may not be possible to continue to maintain the stream banks in the traditional way.
- It is recommended that the traditional technology of stabilizing stream banks with stonework be enhanced with the use of wire or geotextile reinforcement mesh to secure stone walls against heavy stream flow until tree roots can further stabilize banks. Assistance is needed to source and install appropriate reinforcement mesh.
- When heavy equipment is employed without proper hydrological planning, damage can be done to traditional systems of watershed management and food production.
- When projects to stabilize stream banks begin with the deepening of the mouth of the river, the stream bed can be expected to become progressively deeper as a result of stream bank caving. This results in the penetration of seawater further upstream.
- It is recommended that the use of heavy equipment be preceded by proper planning by engineers trained in hydrology and that operators of heavy equipment are either trained in hydrological principles or required to adhere to properly engineered plans.

5. Towards a Watershed Stewardship Framework for Yap

A watershed-based program of land stewardship will be helpful to Yap for a number of reasons:

- A watershed approach helps people, including heavy equipment operators and engineers to understand how their actions impact their environment.
- It would build on and enhance traditional stewardship of watersheds, which is fading with the availability and use of heavy machinery.
- A watershed approach helps adjacent landowners realize that they must cooperate to maintain the health of the area that supports them. Few taro patches exist in isolation.
- The impact of climate change is expected to include increased rainfall and storms. This will require more thoughtful and responsible management of watersheds.

5.1 Watershed stewardship planning

The U.S. EPA Watershed Academy Web (http://www.epa.gov/watertrain) provides training in watershed management and the site (https://wiki.epa.gov/watershed2/index.php/Watershed_Management_Framework) provides a summary for a watershed management framework. The Watershed Management Framework for

Kentucky (http://water.ky.gov/watershed/Pages/WatershedManagementFramework.aspx) provides a good example of the implementation of this framework. These frameworks are largely organizational tools that allow multiple agencies and stakeholders to work together to make the best use of resources in managing the watersheds of large areas. Along with the framework, the US EPA has developed websites with data on watersheds throughout the United States.

A review of the EPA Watershed Framework and other literature shows the need for cooperative efforts between Government agencies and the Private sector including communities and landowners. The importance of Public/ Private collaborative efforts is also emphasized in the FSM National Biodiversity Strategy and Action Plan (2002) and the FSM Strategic Development Plan (2004). On Yap, where most all land is privately owned, but most all funding and heavy equipment is controlled by the government, a public/private collaboration is critical. The Government must require watershed-wise practices for the use of its funding and heavy equipment and information must be provided to assist communities with watershed stewardship. A major product of the Yap Watershed Project is the development of a geodatabase to support decision making by government, landowners and communities wishing to manage their watersheds (step 1 of the EPA process).

5.2. Process of developing a community watershed stewardship plan on Yap

When a group of people concerned about the welfare of their community now and in the future, has access to relevant information ("data"), a number of progressive common sense discussions and actions can be used to develop a watershed stewardship plan. The process described in the next section incorporates features of the frameworks and "tools" developed for larger countries into a Watershed Stewardship Process for Yap. This process also incorporates U.S. Forest Service Criteria and Indicators for Forest Sustainability that cover both ecosystem health and human well-being (http://www.fs.fed.us/research/sustain/criteria-indicators/).

Step 1. Landowner/ Community organization – either traditional or with assistance of Yap Community Action Program

Step 2. Conduct socio-economic survey to determine desired socio-economic benefits to meet community's needs and goals for fresh water, food security, biodiversity, and economic and cultural well-being. PIMPAC has developed a process for doing this.

Step 3. Define area on watershed map. Communities would define the general boundaries of their community and overlay this area on maps of numbered watersheds to determine which watersheds lay within their community. They can then use the watershed maps and databases developed by this project to obtain data on each of these watersheds.

Step 4. Develop watershed summary for selected watershed(s) using watershed database and maps. It is envisioned that Yap Forestry would assist with the development of this Watershed Summary (step 3 of the EPA process) once the community has defined the watershed(s) in which to focus. The summary would include maps, data on the watershed, a general diagram of traditional watershed use, and a SWOT analysis of resources in the watershed. The content of this watershed summary is detailed in 5.3 below.

Step 5. Community conducts more specific and in-depth baseline surveys of most relevant resources and watershed health. These include: a) adjusting the diagram of traditional land use (Appendix 2, 17), to fit their area and current practices, b) identifying especially important resources (fresh water, food security, biodiversity and cultural). The content of these surveys is described in section 5.4 below.

Step 6. Community does a SWOT analysis of select resources and develops a watershed stewardship plan including an action plan, monitoring program, review period and if appropriate, proposal(s) for project(s). Content of a watershed stewardship plan is described in 5.5 below.

Step 7. File plan in accordance with the existing legal framework and with the Protected Area Network framework (when in place).

5.3. Content of Watershed Summary

A summary of accurate and current information available for a watershed is a key part of the watershed stewardship planning process. An initial set of data would include at least the following:

1. A visual overview of the watershed(s). This overview can be constructed by using enlarged sections of the maps in Appendix 2 to better show details of the specific watersheds.

2. Data on watershed(s) derived from the maps and tables in the appendices including size of watershed(s), and the area of many natural features including:

- *Upland Forest – of special interest for biodiversity protection*

- *Agroforest – of special interest in terms of food security, and how much agroforest is within 2 or 5 meters of sea level, or above 6 m of sea level*
- *Secondary Vegetation – as this is area that can be used for gardening without damage to better developed forests. Secondary vegetation with bamboo inclusions (SV.bb) are often favored for gardens. The table also indicates how much of secondary vegetation areas are within 2, or 5 meters of sea level, or above 6 m of sea level*
- *Open land - generally savannas of interest for food security and wildfire vulnerability*
- *Marshes – of interest for food security as potential taro patches*
- *Taro - Presence of four classes of taro patches in three elevation zones, and which are affected by salt water*
- *Potential Taro - Areas suitable for taro patches based on slope and soil type that are within 2 and 5 meters of sea level*
- *Mangroves – of interest for marine productivity and biodiversity protection*

  - For sustaining biodiversity, the following data can be used:
- *Areas identified as "ABS" in the Biodiversity Blueprint for the FSM.*
- *Areas where Terrestrial Protected areas (TPAs) have been established*
- *Areas where Marine Protected Areas (MPAs) have been established*

  - Threats such as vulnerability to wildfires

The database and maps can be used to evaluate connectivity between one natural habitat and adjacent ones. This is an important factor in effective conservation. (It might be noted that the data indicates a lack of connectivity between existing MPAs with adjacent mangroves. This may impact the effectiveness of the MPAs.) In addition, the database will indicate how much area of each watershed is within 2 or 5 meters of sea level, or above 6 m of sea level as this is useful for long term planning for adaptation to climate change.

3. Using Appendix 4, determine how the selected watersheds compare with others on Yap in terms of parameters listed below:

- *Total size*
- *Area within 5 meters of sea level (Appendix 3)*
- *Area of Agroforest and percent of this agroforest is within 5 meters of sea level*
- *Area designated as an ABS within the watersheds including extensive mangroves.*

4. Carry out an analysis of strengths, weaknesses, opportunities and threats (SWOT) for resources in specific watershed(s).

5. Review generalized diagram of traditional watershed use zones on Yap (Appendix 2.17). This diagram describes the integration of Yap's traditional agriculture and land management practices with watersheds, providing connectivity between upper portions of the watersheds and lower wetland and marine ecosystems to maintain watershed functions while supporting people. General management strategies for each zone are given in a brochure prepared by the project (Appendix 2.20)

5.4. Community surveys and analyses

After completing the steps above, communities would then conduct surveys to enhance the general watershed summary and collect information specific to their watershed(s) and objectives. Steps in this process could include:

1. Community adjusts general diagram of traditional land use zones (Appendix 2.17) to fit their area and its current use. Communities would generate maps of these zones in their own areas to use as a guide in planning watershed management activities.

2. Conduct baseline surveys of most relevant resources and watershed health. U.S. Forest Service Criteria and Indicators for Forest Sustainability that cover both ecosystem health and human well-being (http://www.fs.fed.us/research/sustain/criteria-indicators/) are indicated with italics in the steps that follow.

3. *Monitor freshwater resources* - Some specific protocols for monitoring of watershed health are provided in Komoto (nd ca 2010). (*Criteria 4 c: Conservation and Maintenance of Water Resource*s)

4. *Determine biodiversity (Criteria 1: Conservation of Biodiversity)*

- *Use species lists for each main vegetation and ABS site derived from vegetation reports (Falanruw et al. 1987 & Falanruw 2015)) complemented by community surveys*
- *Categorize species lists into: rare endemics, endemics, native species (including whether species occurs in mature or secondary forests or requires special conditions), introduced species, weed species, invasive species, and culturally and economically important species)*
- *Use categorized biodiversity lists evaluate biodiversity value of sites*
- *Use species lists evaluate timber and non-timber resources (Criteria 2: maintenance of anthropocentric productive capacity of forest ecosystems, and 3: food security)*

5. *Evaluate health of watersheds, forests and downstream marine habitats*

- Evaluate connectivity between natural communities (including impacts of factors such as access roads, infrastructure such as airstrips, etc.)
- Evaluate connectivity between terrestrial and marine communities & presence of marine ABS and MPAs

- Evaluate condition of rivers; presence of native fauna, blockage, erosion and siltation.
- Evaluate current status of watershed protocol indicators, including condition of interior of natural communities.
- Determine where forests should be protected to preserve or enhance soil and water resources *(Criteria 4: conservation & maintenance of soil & water resources)*
- Determine important areas for maintenance of *forest contribution to global carbon cycles (Criteria 5)*, reference Donato et al (2011, 2012)
- Evaluate threats to watersheds & forests including incidence of invasives, pests and diseases (References Yap State 2009, Cannon 2016), *(Criteria 3: maintenance of ecosystem health & vitality)*
- *Develop a Community Wildfire Preparedness Plan (TRCT 2010) and obtain wildfire suppression training (USFS Fire and Aviation training 2015)*
- Evaluate biotic processes & threats (diseases, pests, invasives)
- Evaluate physical threats (typhoons, bulldozers, large-scale development projects, fire, pollution, climate change, unwise farming systems, etc.)
- Evaluate erosion and siltation, especially along streams

6. *Evaluate food security (Criteria 6: Maintenance & enhancement of long-term multiple socioeconomic benefits to meet the needs of societies)*

- Determine area of agroforest (Appendices 3.1, 3.3 and 4.2), Survey agroforests using criteria developed for agroforest (Appendix 5)
- Determine location and percentage of taro patches vulnerable to salinization Appendix 2 maps 8 and 9).
- Determine if salinized taro patches can be revived by reapplication of traditional practices including those described in Section 2.3
- Determine how to meet needs for taro from areas not vulnerable to salinization
- Determine established area available for meliy gardens
- Determine area needed to provide food security via mix of agricultural systems

6. *Identify areas of special cultural value* (work with Historical Preservation Office (HPO)

7. *Identify areas that could be developed for economic and other uses, and describe conditions needed to prevent damage to watershed health, aquatic resources, food security, biodiversity and cultural integrity.*

5.5. Community watershed stewardship plan

In general the objective of a watershed stewardship plan is to use each zone for its highest value use. In some cases, the highest value use of an area may be for its ecological services. An example is mangroves, which are keystone habitats critical for both the protection of the lagoon and fisheries as well as protection of the land from storm surges. The highest use of other areas may be for food security or for biodiversity protection. Yap's agroforests are an example of areas that are most valuable for food security while wild forests are most valuable for maintaining biodiversity. Other areas may be important for cultural and economic well-being. If managed appropriately, areas such as agroforests can be used for their ecological services as well as food security and cultural and economic well-being. The watershed stewardship plan would be based on the watershed summary, community surveys, community specific SWOT analyses, and have the following components:

- Watershed summary with maps
- Results of community surveys and SWOT analysis
- Strategies for protecting freshwater resources, food security, biodiversity, community wildfire protection plan (CWPP), cultural heritage and ecologically sustainable economic development. Cultural heritage strategies would be developed with Yap's HPO program. Examples of some strategies for food security and biodiversity protection are given in section 6.
- Priority action plan and proposals for project(s)
- Monitoring program - describe monitoring protocol, including who will do monitoring, data access and ownership, and how data will be used to achieve an adaptive management program
- Planning cycle for evaluation and adjustment of plan
- Filing of plan in accordance with existing legal framework and with protected area network legislation when it is passed

5.5.1.Strategies for food security, biodiversity protection

Apply strategies for community-specific land use zones (for general zones see Figure 17), complemented by best practices, both traditional Yapese and modern. Examples include:

- Use best practices (traditional or modern) to achieve food security such as developing taro patch habitat not vulnerable to salinization through stream bank stabilization enhanced with mesh, use of traditional diversion swales and check dams, and development of upland taro patches. Develop 'piers' to access interior of large taro patches. Develop new "beside the house" taro patches for working women. Renovate floating taro patches.
- Develop enhanced methods for *meliy* gardens that can extend the use of the garden and reduce the opening of new areas, and enhance soil development during the fallow period.

5.5.2. Develop strategies to protect biodiversity. Develop community protection and recovery plans for: rare endemic species, invasive species management, management of pests and diseases, develop community wildfire protection plan (CWPP), erosion & siltation management program to protect both terrestrial and marine environment.

- Determine if areas should be developed into Terrestrial Protected Area (TPA) under Micronesia Challenge and Yap State Protected Area Criteria and Portfolio for Terrestrial Protected Areas, and develop adaptive management plan specific to terrestrial protected area.

6. Summary Discussion and Recommendations

This project uses GIS technology to provide a watershed-based approach to food security and sustaining biodiversity on Yap. It provides a collection of GIS-produced maps and a geodatabase that can be used to develop and evaluate projects promoting Yap's food security and biodiversity. The GIS work is complemented by a survey of relevant watershed literature as well as traditional technologies for managing watersheds. Projects carried out in four villages provide lessons on benefits and challenges of traditional stream management. Results of these efforts contribute to a watershed framework for Yap. Lessons learned from this project in relation to GIS, watershed management, food security and sustaining biodiversity are presented below.

6.1. GIS lessons. Outcomes of GIS-based analysis are limited by the quality of the data used. As noted in the Methods section, aligning data sets created at different times and scales, by different organizations, using different native geodetic datums, and to meet different objectives is inherently difficult. Three data sets fundamental to this exercise (e.g., soils, vegetation, streams) were created in the 1980s by different US government agencies. In addition, because this project's driving question concerns coastal process dynamics of a small island, the spatial accuracy of elevation estimates is critical. The DEM generated "coast line" can only be considered an approximation both horizontally (i.e., mangroves blur the line between terrestrial and aquatic) and vertically (i.e., the forced minimum elevation of 1 m). The net result of these data-driven caveats is that one must be comfortable with a certain level of imprecision and ambiguity in the results.

There are four main lessons learned by using GIS to assess food security on Yap. First, from anecdotal data, sea level rise is already having a noticeable impact on taro production up to an estimated elevation of 5 m. This is occurring throughout Yap, though the anecdotal reports have yet to be field-tested. Second, because an estimated 68% of Yap's best taro-producing land is located under 5 m elevation, future food production will be significantly impacted by even current levels of sea level rise. Third, though all of Yap will be impacted by sea level rise, the degree of impact on future taro production will vary between Yap's municipalities. Some will have a significant portion of their best taro-growing area degraded, while other municipalities will be less impacted. Fourth, because of the concentration of Outer Islander settlements in certain municipalities (e.g., Gagil, Tomil), future food demand will also vary between municipalities. It is not yet clear how these future trends (i.e., impact on food production, shifting spatial pattern of food demand) will interact. Regardless of the specific future conditions, it is clear that GIS will be a valuable tool to describe, analyze, and respond to these challenges.

6.2. Watershed management. Given Yap's high rainfall climate and topography with low-lying coastal areas, it is likely that early Yapese encountered an island with a swampy coastal zone. Although this area was waterlogged, living near the coast was advantageous for access to marine resources. The landscape was modified to provide for drained areas for living structures and deepened areas for taro patches. Even today the watershed management technologies of earlier Yapese remain written on the landscape in the form of systems of ditched beds, water management systems, taro patches and raised paths and house platforms.

Our survey of watershed literature revealed many methods for managing water flow and erosion such as swales, rain gardens, streambank stabilization, gabions, riprap, and other methods. Initial interviews with Yapese practitioners of traditional technologies focused on methods of drainage, erosion control and streambank stabilization. Discussions with elders and field observations suggest however, that drainage and erosion control are only part of the story. Yapese also managed silt, the depth of the water table, and the interface of fresh and marine waters as described in section 2.

A lesson learned from our review of both scientific watershed literature and traditional technologies is that many of the technologies recommended in the literature are already practiced on Yap, and those that are not, require more land area and resources than are available on Yap. A recent publication: Storm Water Management in Pacific and Caribbean Islands, a Practitioner's Guide, by the Horsley Witten Group, Center for Watershed Protection (2014) describes "a LID (low impact development) approach to improve water quality, treatment, rainwater use and recharge to better protect paradise" (Horsley Witten 2014: p.2). They provide BMP (best management practices) to protect coral reefs, maintain aquifers, and collect precious rainwater resources using rain gardens. On Yap, "rain gardens" (Horsley Witten 2014) are called *milboquch* taro patches. In general, this guide recommends many practices that Yapese use, and thus serves to legitimize these traditional practices.

6.3. Food Security

While it was not included in the scope of the original proposal, initial work revealed the need to collect data on the incidence of taro patches and local garden sites. No data has ever been collected on these important parameters of food security. We therefore undertook the additional task of surveying the location of local garden sites and taro patches, also noting whether local residents reported salinization. The result of this effort is a remarkable fusion of traditional knowledge and modern GIS technology.

A major lesson learned from mapping the location and salinization of taro patches is the current vulnerability of this major food production system to sea level rise. The first three months of 2016 has also demonstrated the vulnerability of smaller dug taro patches to drying up during severe post El Nino droughts. This data raises serious concerns about Yap's food security in an era of climate change and sea level rise, especially at a time when aid funds under the Compact of Free Association II are declining and Outer Islanders, who make up about 40% of Yap's population, are moving from their low-lying islets to the higher ground of mainland Yap.

The projects undertaken by the villages of Atelieu, Okau and Rikin involved stream bank stabilization. Given the villages' limited land area, these projects were necessary in order to maintain foot paths and to avoid flooding of living areas. They were also needed to prevent the stream from meandering into taro patches and carrying away the accumulation of rich silt needed to grow taro. In the past ditches were dug above streams to divert excess water. The depth of these ditches had to be managed so that they were not deeper than the taro patches, lest they lower the water table and dry up the taro patch. The project in Riken also provided a lesson that removing too much of the forest canopy can result in rampant growth of weeds that can clog the river. This was corrected in the second phase of the project.

Another lesson learned is that watershed management objectives should not only include management of erosion and the drainage of swampy areas, but management of silt in taro patches,. The management of the level of the water table contributes to healthy taro patches, and to the maintenance of a reservoir of freshwater. In an era of sea level rise, the traditional use of diversion swales and check dams discussed in Section 2.3 can be used to extend the life of taro patches both on Yap and in other areas of the Pacific with coastal taro culture.

Today many coastal taro patches have been killed or damaged as a result of road building activities. Bulldozing and landfilling with heavy machinery often result in erosion and siltation that smothers taro patches. Whereas the stone paths of the past allowed fresh water to drain, the impermeable roads of today prevent the drainage of taro patches so that taro patches are drowned and convert to *Phragmites* marshes. In addition, the former management of saltwater intrusion has been altered by the installation of large "*docan*" culverts that enable salt water to penetrate further inland, killing taro patches, and converting some to *Nypa* swamps.

Traditionally, some brackish coastal depressions known as "*marieu*" were utilized for retting coconut husks so that the fibers could be used for making twine and rope. With greater pressure for development of coastal areas today, there is a tendency to fill such areas and to channelize adjacent streams. Some recent projects to stabilize river banks on Yap have resulted in the deepening of the river bed as a result of the force of water from excessive rainfall being forced to flow through a constricted river rather than overflowing onto a "*marieu*", swampy area, or "flood plain". As a result of the deepened river bed, there is more drainage of fresh water upslope and a lack of a reservoir of fresh water pressure to prevent the intrusion of salt water upstream as is happening in places such as Dugor and Wanyan, Yap.

Western watershed ecologists have come to realize that it is important to maintain even brackish wetlands and swamps to serve as flood plains and to provide wildlife habitat. An indicator of brackish swamps on Yap are *Nypa* palms and *Dolichandrone spathecea* trees. The IUCN Redbook recognizes the latter species as decreasing and in need of updated information. This may be a result of the popularity of projects to "reclaim" swampy lands throughout the area in which this tree occurs.

In addition to the disregard for taro patches by road engineers and heavy equipment operators, the work force devoted to taro patches is declining. It is remarkable and inspiring how many women, even those with professions such as lawyers and doctors, continue to maintain their taro patches inasmuch as the hours of the day and evening allow. Nonetheless, more knowledgeable older women are relegated to babysitting for daughters with salaried jobs, or are passing away. In some cases, taro patch culture has not been passed onto the next generation as women have gone off-island for schooling or entered the salaried work force and do not have as much time for tending taro patches. Increasingly, taro patches are, of necessity, harvested without the former attention given to replanting, cleaning, shade management and management of water banks and flow. Today, the careful management of flowing water that characterized traditional Yapese agriculture is being replaced by the less sophisticated use of heavy machinery and the Yapese heritage of landscape architecture is fading away.

6.4. Sustaining Biodiversity

A logical adaptation to salinization of coastal taro patches is to move agricultural activities upland. Taro patch resources are not as abundant upland however. Climate change predictions call for higher levels of rainfall, and this will impact traditional gardens that require an initial dry period. Adjustments in the agricultural system will be needed. If agricultural activities are moved upland however, there will be increased pressure to convert Yap's limited area of forest to food production. This will seriously impact biodiversity. While shifting gardens are generally made in areas of secondary vegetation closer to home, women are keen to make use of forested lands when they become available as they promise higher yields for less labor as the soil is more fertile and friable and there is less of a weed problem. There are numerous examples such as the road from Dugor to Atelieu and the roads to Tabiwol and Ruu' where forest was rapidly converted to gardens for one or a few years followed by secondary vegetation and repeated burning. Serious planning and improvement of both food production systems and efforts to sustain biodiversity and ecosystem productivity are needed.

6.3. Recommendations

This project provides a geodatabase to assist both government and communities to develop watershed stewardship plans and projects. Some recommendations include:

- A project to field-validate anecdotal reports of saltwater intrusion in taro patches. This project has mapped a number of taro patches that have been reported to be affected by salt water as lying within 5 m of sea level. A GIS analysis has indicated that some 68% of land suitable for taro patches (based on soil type and slope) is located within 5 m of sea level. It is therefore very important to field-validate locations and degree of salinity of taro patches in order to plan for future food security. A proposal for support for this work has been submitted.
- An expanded program of monitoring aquifers. While this project focused on food security and biodiversity protection, a major concern of watershed projects is the monitoring and protection of aquifers. There appears to be minimal monitoring of levels of fresh water in Yap's aquifers and no monitoring of the interface of fresh water and seawater. The salinization of freshwater aquifers is difficult to reverse and such monitoring is needed.
- A renovation of traditional water diversion swales and check dams in order to retain growing media in taro patches and prevent progressive stream bank caving and sea water intrusion.
- A plan to educate Public Works personnel on the importance and methods for maintaining not only roads, but also the taro patches and other wetlands that they impact, and of the locations of areas of special biodiversity and Yap's commitment to the Micronesia Challenge.
- A program to assist local gardeners with the development of home gardens and improved methods of managing shifting gardens. The making of shifting gardens requires the opening of the forest canopy. If the forest occurs in areas designated as areas of special biodiversity significance, then the goal of food security is at odds with the goals of the Micronesia Challenge. Improved gardening methods in areas of secondary vegetation would remove pressure from native forests.
- Projects to renovate and revitalize agroforests and extend them upland. Agroforests are valuable in many ways. They protect watersheds and are Yap's most resilient and productive agricultural system. They are very important for food security and also for economic value. An analysis of market records for 1973 – 1992 (Falanruw 1995), the only data available on Yap's agricultural production, showed that some 91% of market sales were for produce grown in agroforests. Today, Yap's biggest export is betel nut, a product of agroforests. While Yap's agroforests do not always include wild native species, they are rich in agrobiodiversity and meet Yap State criteria Yap State Criteria for Terrestrial Protected Areas.

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