Wetlands Ecol Manage
DOI 10.1007/s11273-013-9288-4

ORIGINAL PAPER

Palau's taro fields and mangroves protect the coral reefs by trapping eroded fine sediment

Shirley Koshiba · Meked Besebes · Kiblas Soaladaob · Adelle Lukes Isechal · Steven Victor · Yimnang Golbuu

Received: 12 February 2013 / Accepted: 15 February 2013

Abstract Sedimentation is one of the biggest threats facing coral reefs, not only in Palau, but everywhere in the world where there are reefs within reach of river plumes. Due to Palau's largest island of Babeldaob's steep topography, high rainfall, and highly erodible volcanic soil, erosion has been exacerbated by recent increases in land-use. Studies have documented the negative impacts of the resulting sedimentation on coral reefs around Babeldaob. Similar studies have shown that mangroves can trap about 30 % of the fine eroded sediment from land. This paper documents the filtering effects of cultivated wetland, namely that of taro (*Colocasia esculenta*) fields, which are natural wetlands used to grow taro, a source of starch for the population. A 4-month long field study was conducted to quantify the sediment accumulation rate for three different types of taro fields and to determine their sediment trapping efficiency. The results showed that the taro fields have the capacity to trap up to 90 % of sediments. We suggest that the sediment trapping capacity of mangroves and taro fields mitigated the negative impacts of soil runoff on coral reefs around Babeldaob while the island was being inhabited by early Palauans for many generations.

Keywords Sedimentation · Taro field · Mangrove · Coral reefs · Sustainability · Palau

Introduction

Palau is an island state located in western Micronesia in the northwestern Pacific Ocean, situated north of Irian Jaya in Indonesia and east of Mindanao in the Philippines (Fig. 1). Stretching approximately 700 km along a northeast-to-southwest axis, the Palau Archipelago represents the exposed crest of the Palau-Kyushu Ridge. There are over 500 islands with a total land area of Palau of 487 km^2. Babeldaob Island, a high volcanic island, is the largest of all islands with an area of 334 km^2. Palau has a tropical climate, with high temperatures and humidity throughout the year. Average annual rainfall is 3.7 m with a dry period from January to April (Kayanne et al. 2007).

Palau has some of the most diverse and spectacular coral reef ecosystems in the world (Richmond et al. 2007), which provide many important services to the

S. Koshiba (✉) · A. L. Isechal · Y. Golbuu
Palau International Coral Reef Center, 1 M-Dock Road, P.O. Box 7086, Koror 96940, Palau
e-mail: sdkoshiba@picrc.org

M. Besebes
Belau National Museum, P.O. Box 666, Koror 96940, Palau

K. Soaladaob
United Nations Joint Presence (GEF-SGP), Suite 301, 3rd Flr. Surangel Building, Koror 96940, Palau

S. Victor
The Nature Conservancy, Palau Field Office, P.O. Box 1738, Koror 96940, Palau

Published online: 21 March 2013

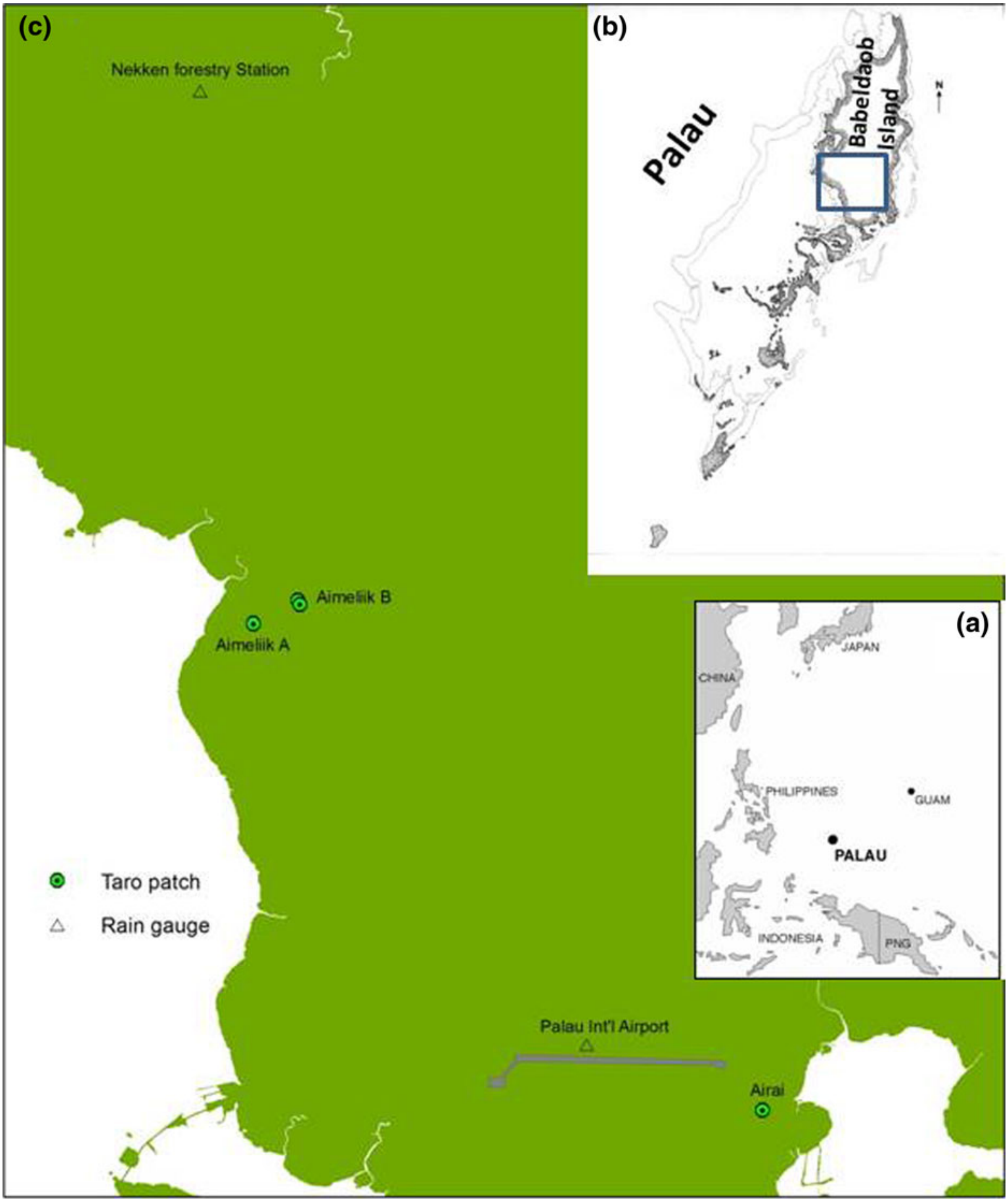

Fig. 1 **a** A location map of Palau, **b** a location map of Babeldaob Island showing the study area, the lagoon that is sheltered by a barrier of coral reefs, **c** a map showing the location of the taro fields in Babeldaob and of the rain gauges

people of Palau. Despite their importance, coral reefs of Palau have come under increasing pressure resulting from both anthropogenic and natural causes (Kayanne et al. 2007). Anthropogenic disturbances include increased resource use and resource extraction (Golbuu and Friedlander 2011), Land-use changes and intensity has increased sedimentation, resulting in damages to reefs near the coast of the Babeldaob Island (Golbuu et al. 2011). Similar negative impacts of sedimentation on coral reefs as a result of increased soil runoff resulting from poor land-use practices is well documented (Fabricius 2005; Victor et al. 2006; Golbuu et al. 2008) Runoff from land affects coral reefs in several ways; it increases the nutrient levels on reefs (both inorganic and particulate organic matter), it decreases light levels due to increased turbidity, and increases rates of sedimentation in coral reef areas (Fabricius 2005; Golbuu et al. 2011). Contrary to other Pacific Islands, Palau has a long history, possibly dating back 2,000 years ago, of sustainable resource use (Diamond 2005). This paper advances one hypothesis of why Palau has sustained a large population for over 1,000 years, without depleting its own resources.

Wetlands are known to be effective sediment filters. Studies have shown that mangroves can trap between 30 and 60 % of sediment from land, therefore preventing them from reaching the reefs (Victor et al. 2004, 2006; Golbuu et al. 2003). Taro fields, a natural wetland constructed for growing the taro plant, an important food crop in Palau (Fig. 2) may have some filtering capacity.

The structure of *mesei*, taro field, initiated by the early Palauans, has been maintained to this day. Their development, probably mostly after about A.D. 1200 to 1300, was presumably the culmination of accelerated erosion in the island's interior following extensive clearing of the vegetation on slopes. Sediment analyses, radiocarbon dating, and archaeological investigations indicate substantial inland land disturbance starting around 2,400 years ago (Liston 2009). These findings almost certainly signify cultural use of interior Babeldaob by this time, including the onset of major earthwork (terrace) construction. Intensive and extensive inland use continued for about another 1,200 years. The continuous deposition of inland eroded soils expanded the coastal plains and formed expansive fertile wetlands (Liston and Tuggle 2006; Liston 2009, 2011; Athens 2011).

Traditional management of taro (*Colocasia esculenta*) cultivation in Palau can be considered a type of intensive agricultural method found in societies that possess a complex social structure that is reflected in traditional Palauan society. Taro cultivation in Palau is

Fig. 2 Photo of a typical cultivated taro field in Palau showing different planting stages of taro to provide a continuous cycle of food supply. The upper right *inset* shows that the stream, with its water and fine sediment, is diverted to the taro field. Photo courtesy of Faustina K. Rehuher-Marugg

an amalgamation of skills and knowledge for both the plant and agricultural system. In other parts of Micronesia, taro is planted in well drained mixed gardens or ditches (Falanruw 1980; Englberger et al. 2009). Palau's taro cultivation is commonly grown in swampy areas (often man-made) in the lowlands usually just upstream of the mangrove areas. Culturally in Palau taro fields were tendered by women.

A taro field is protected by embankments. Water is diverted from the stream to the taro field(s), thus creating an inflow of water into the *mesei* (McKnight and Obak 1960; Bammann and Wey 1991). An outflow is created at the downstream end of the taro field to allow excess water to flow back into the main stream. The irrigation system allows water to enter on top and the side of the soil as well as bottom of the soil). The field is protected by embankments. This structure ensures a steady flow of water that neither dries up the *mesei*, nor being overwhelmed by too much water. Maintaining the water flow of the *mesei* requires constant cleaning of the divides to prevent blockage from debris and weeds as well as avoiding water stagnancy (Renguul, personal communication: 2012). Skilled women would regulate and manage the water flow into the taro field based on weather and cultivation cycles.

There are a number of plant species found within and around the boundaries of an individual taro field. Plants around the boundaries are usually those in which women use to cultivate or use as medicinal herbs, and much more. Bananas, betel nut, and the coconut are the most common. Within a taro field, there are various herbs planted for hygiene or for treatment of the fields. However, food crops are the *Cyrtosperma merkusii* (*brak*) and the *Colocasia* (*kukau)*. A typical formation of the taro field consists of the *Cytrosperma* planted around or on the edge of a taro field with the *Colocasia* planted within (Fig. 2).

Culturally, *Cyrtosperma* is treated as a food source for famine where it has has high resistance to saltwater and longer plant life (3–5 years); it's a rich source of starch in times of droughts and other natural disaster. *Colocasia*, on the other hand, is viewed as prestigious source of food in Palau. Whereas *Cyrtosperma* requires little tending once it has been planted *Colocasia* is more delicate for its fragility and shorter plant life (8–12 months). Therefore more efforts are spent tending *Colocasia* than *Cyrtosperma* (McKnight and Obak 1960; Bammann and Wey 1991). Although both are eaten quite often, *Colocasia* can be found in many aspects of Palauan cultural practices (funerals, first birth ceremonies, transfer of title ceremonies) and used symbolically in chants, dances, proverbs, and stories with moral lessons (Palau Society of Historians 2008).

Tilling the soil in taro fields

When tilling the soil or adding organic fertilizer, two methods can be applied to ensure taro plants grow well. Some areas in Palau use a method called *mesalo*. This form of tilling is when women gather leaves of certain plants (*ramk*) and bring them into their taro field. Women use *omult*, a process where soil are lifted from the bottom and replace it with the soil on top with the *ramk*. In this method the taro field is called a *mesei* which enables women to plant taro and let it grow for 8 to 12 months until harvest time (McKnight and Obak 1960). Another tilling method is utilizing grass growing in the taro field as fertilizer. Rather than clearing and throwing grass out of the taro field, women trudge on the grass, or mesarch, pushing with their feet to mix them in with the bottom soil (Renguul, personal interview: 2012). The taro field is then called a *dechel*. Once a substantial area has been tilled taro plants are planted. In this method women clean out weeds, however herbal plants grow wild in taro field are left for filtering and well being purposes of the crop and soil.

The structure of the taro field, regulation of water flow, and management of *mesei* in Palau has continued for many generations and has been passed down between families and their women. This culture of taro and agriculture has shown to be a critical part of Palauan life and reflects the complexity of Palauan social structure that we see to this day. It is believed that the taro field plays a role in mitigating environmental degradation of coastal marine areas through its filtering capacity. The objectives of this study were to: (1) quantify the sediment trapping rates for different types of taro fields (2) determine the sediment trapping efficiency of taro fields.

Methods

Study area

Three sites were selected for this study. All three sites were located in the island of Babeldaob. The first site was a cultivated taro field located in Airai in south eastern part of Babeldaob with a surface area of 131.9 m^2 (Fig. 1). It was located in close proximity to a residential area and adjacent to a secondary unpaved road. The second site, Aimeliik A, was a cultivated taro field located in Aimeliik and had a surface area of 1,394.5 m^2 (Fig. 1). It was situated downhill of a steep slope that has undergone extensive forest clearing. The third site, Aimeliik B, was an overgrown taro field also located in Aimeliik and was downhill of a paved road adjacent to a forest that has been cleared and replanted with beettlenut trees (Fig. 1). It had a surface area of 674.5 m^2.

Collection and processing of sediments

Forty-four bottom-mounted sediment traps (5.2 cm diameter, 61 cm height), were deployed in pairs, and retrieved monthly from June to September 2012. The traps were driven into the mud, leaving about 2 cm of the trap above ground. In Airai, 14 sediment traps were deployed along a transect in the taro field (Fig. 3). For Aimeliik A, 16 sediment traps were deployed throughout the taro field, following the general flow of water, with 4 sets of traps located at the base of the steep slope that has undergone extensive forest clearing. These traps were scattered along the location of sediment source, since the steep slope could contribute sediment at several points. In Aimeliik B, a stream separated two taro fields; 2 sets of sediment traps were deployed in the stream, while another 8 sets of sediment traps were installed evenly on both taro fields. The sediment traps were deployed in pairs along a transect moving away from the entry point of water into the taro field.

The traps were retrieved on an average of 30 days to measure accumulated sediments. In the laboratory, sediments were oven dried and weighed using an analytical semi-micro balance (A&D™ GR-120) to estimate total sedimentation accumulation rates (mg dry weight cm^{-2} d^{-1}); the dried sediment was burned at 600 °C for 2 h to remove organic matter and weighed again.

Rainfall data

Daily rainfall data were collected at the Palau International Airport located in Airai State and Nekken Forestry Station located in Aimeliik State (Fig. 1) by the National Weather Service.

Results

The amount of sediment accumulation measured in the three taro fields differed during the study period (Table 1). Most of the sediment was inorganic with a mean organic content of 4.6 % (±2.1 %). Aimeliik A accumulated over five times more sediments than Aimeliik B and Airai sites, because of a higher rate of erosion in their catchment; Aimeliik A site was located at the foot of a rapidly eroded hill where the vegetation had been cleared.

Sediment accumulation rate for each taro field varied widely during the 4 month study period. The variation in the monthly sediment accumulation rate followed weakly the variation in monthly rainfall ($r^2 = 0.25$). In Airai, sediment trapping by the taro field was highest during the months of June and September and lowest during the months of July and August, corresponding to rainfall data that showed the same pattern. For both Aimeliik A and Aimeliik B, the highest rate of sedimentation was in August, while rainfall data was highest during the month of July (Table 1).The sediment accumulation rate decreased with increasing distance from the entry point of soil runoff into the taro field (Fig. 4). Based on the decrease in accumulation rate from trap 1 to trap 6, the Airai taro field trapped on average about 90 % of sediment entering into the field. A similar value of 90 % was also observed in the other two taro sites (not shown).

Discussion

The results of this study showed that the three taro fields differed in the amount of sediment accumulated during the study and these results were consistent with the different observed land-use intensity in their catchments. In Aimeliik A site, where the highest level of sediment accumulation was recorded (Table 1), the adjacent steep slopes had been recently cleared. The area had been cleared of the understory vegetation and while the largest trees were left standing, vegetation clearing was enough to cause measurable amount of soil erosion as evidenced by the

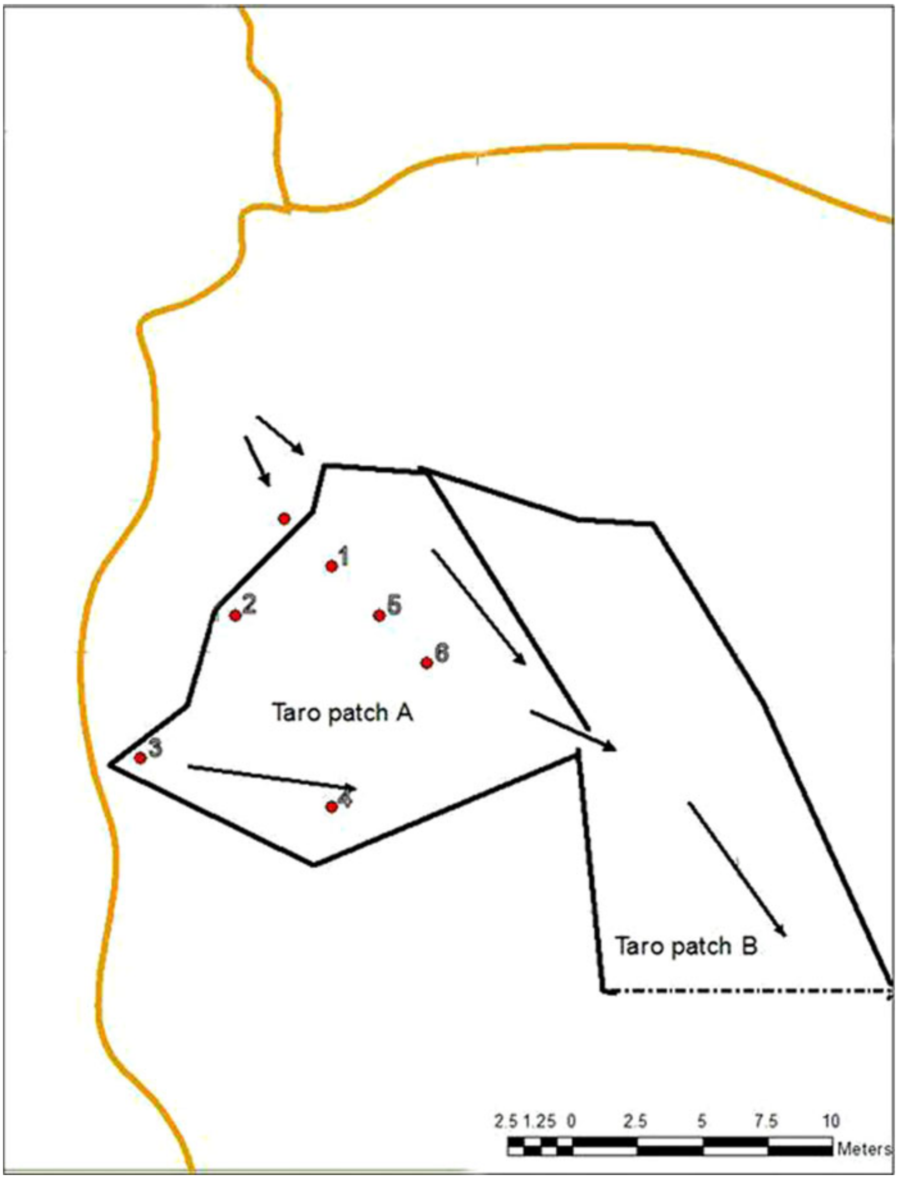

Fig. 3 A map of the Airai taro field. The *dots* indicate the location of the sediment traps, the *thick line* indicates a dirt road adjacent to the taro field, the *arrows* represent the drainage pattern, while the *solid black line* is the raised dry land boundary of the taro field, and the *dotted line* signifies that Airai taro field is connected to another taro field and is not bounded by dry land

Table 1 Monthly sedimentation rates at the 3 sites and monthly rainfall during the 4-month study period

	June	July	August	September	Average	SD
Sedimentation rate (kg month^{-1})						
Airai	879.4	390.6	495.9	505.1	567.8	214.2
Aimeliik-A	8223.0	5778.3	7983.8	6583.5	7142.2	1161.7
Aimeliik-B	1095.5	1694.2	3177.1	1737.1	1926.0	884.0
Rainfall (cm month^{-1})						
Palau Int'l Airport	43.5	52.8	40.2	52.6	47.3	–
Nekken forestry station	18	33.1	–	–	25.5	–

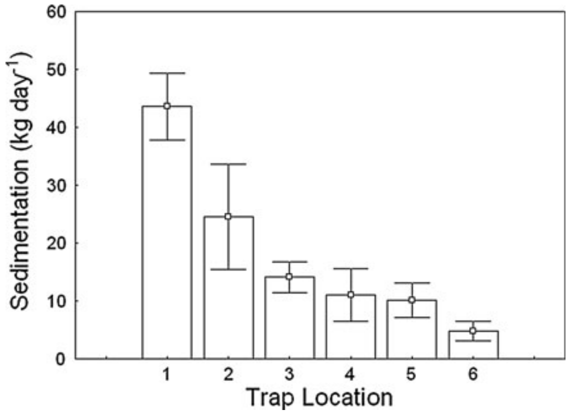

Fig. 4 Sediment settling rate (kg/day) by trap locations in Airai taro field. 1 indicates the trap closest to the source of sediment inflow into the taro field, and 6 being the farthest from source of sediment inflow. *Error bars* indicate standard errors

formation of small gullies along the slopes (not shown). The land owner was using logs to slow down water flow.

In Aimeliik B, where the adjacent upland areas were cleared several years ago but were vegetated during the study, soil erosion was very obvious by the presence of growing gullies along the slopes (not shown).

Lower amounts of sediment were measured in the Airai taro field where there was intensive farming less than 500 m upland and an unpaved road, which were expected to contribute higher amount of soil runoff into the taro field. This suggest two possible explanation of lower soil runoff than expected, namely (1) the road has been compacted by the cars using the road; (2) the slope of the land is not as steep to cause high rate of soil erosion compared to Aimeliik and thus contributed less soil runoff. Thus land use intensity alone was not a good indicator of potential for soil erosion, other factors such as the slope, rainfall intensity, topography, and compactness of the soil, and the age of the clearing, are also important in determining susceptibility for soil erosion (Toy et al. 2002).

While sediment accumulation rate varied between the three taro fields because of different sediment loads from their catchments, the sediment trapping efficiency of the three taro fields was similar at 90 % on the average. The trapping efficiency of taro fields could be a result of water flow management in the taro field. All taro fields are designed so that water enters from the stream and exits back into the stream at an outflow that was overgrown with grasses. The taro plants themselves and the plants leaves, i.e. banana leaves, which are used for managing grass growth also impede water flow (Fig. 2). This essentially restricted the outflow of water carrying sediment and increased the residence time. In addition, as the water entered the taro field, it was dispersed across the width of the taro field, thus slowing the water flow. The depth of water as it was dispersed across the field was typically 50–10 cm from visual observations. This allowed the fine sediment to fall out of suspension quickly in the taro fields.

Conclusion

The use of water runoff in irrigation of taro fields and the traditional practices of managing taro fields decrease the export of terrestrial fine sediment to coastal waters and coral reefs (McKnight and Obak 1960; Bammann and Wey 1991; Masse et al. 2006; Golbuu et al. 2011). Even if the taro field continually accumulated sediment, it remained viable without eventually drying up because the women often let the taro field and the associated irrigation system get overgrown with grass to maintain the water level in the taro field as well as the water in the irrigation channels. During periods of rainfall events, the grass helped reduce water flow allowing sediment to settle. The women often cleared the irrigation and the taro field as sediment accumulated; the accumulated sediment was often piled on the sides of the taro field creating an embankment that divides taro fields, essentially creating a barrier that prevented further runoff from entering into the taro field (McKnight and Obak 1960; Bammann and Wey 1991). This allowed for control of water and sediment in the taro field. This practice helped maintain water balance in a fine balance between water and sediment that kept the taro field from becoming stagnant while continuing to be productive. And most important of all, it kept the soil on land and kept the taro field productive. Thus, the practice of agroforestry and water management in the taro field helped reduce degradation of coastal areas from increased sedimentation.

The results of this study show that taro fields are able to trap sediments, similar to the sediment trapping capacity of mangroves. Additional study to quantify the amount of soil runoff into the taro fields and the extent of taro farming throughout Palau, together with the known sediment trapping capacity of mangroves, would allow us to quantify the sediment budget of Palau both historically and at present.

Because of the Palauan traditional management of water flow into and out of the taro field, continued taro field cultivation is encouraged for the trapping of sediment in the taro fields. Not only are taro fields vital for buffering marine environments, they also provide crops that have been a major source of starch for the people of Palau. While the use of taro as a food staple is decreasing because of the import of rice, it is still widely eaten, especially during customary and cultural events. The promotion of the continued use of taro farming has the dual benefit of providing for food security as well as buffering coral reefs from impacts of soil erosion.

Acknowledgments This study was supported by NOAA Coastal Oceans Program, The Nature Conservancy, The Palau International Coral Reef Center, and The Belau National Museum. The authors wish to thank Arius Merep, Asap Bukurrou, Geory Mereb and Dawnette Olsudong for their assistance during this study as well as the taro field owners Dwight Masami, Rikel Nakamura, and Dirrurcherudel Didil Dengokl Nakamura for allowing the study to be conducted in their taro fields.

References

Athens JS (2011) Paleoenvironmental contributions. In: Liston J (ed) Archaeological monitoring and emergency data recovery for the Compact Road, Babeldaob island, Republic of Palau. Historic preservation investigations, Phase III. Volume XII: lab analyses, discussion, syntheses. Prepared for US Army Corps of Engineers, Pacific Ocean Division, Hawai'i. International Archaeological Research Institute, Inc., Honolulu, pp 521–524

Bammann H, Wey H-W (1991) The cultivation of taro in the Palau Islands (Micronesia): a survey of traditional and recent cultivation practices. Palau Community Action Agency, Koror, p 82

Diamond J (2005) Collapse: how societies choose to fail or succeed. Penguin Books, New York

Englberger L, Albert K, Lorens A, Levendusky A (2009) Taro: an important Pohnpei staple food in ethnobotany of Pohnpei: plants, people, & Island culture. University of Hawaii, Honolulu, pp 132–162

Fabricius K (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Mar Pollut Bull 50:125–146

Falanruw MC (1980) Taro growing on Yap, in Research extension series, Hawaii. Institute of Tropical Agriculture and Human Resources. Honolulu, Hawaii, p 105–109

Golbuu Y, Friedlander AM (2011) Spatial and temporal characteristics of grouper spawning aggregations in marine protected areas in Palau, western Micronesia. Estuar Coast Shelf Sci 92:223–231

Golbuu Y, Victor S, Wolanski E, Richmond RH (2003) Trapping of fine sediment in a semi-enclosed bay, Palau, Micronesia. Estuar Coast Shelf Sci 57:941–949

Golbuu Y, Fabricius KE, Victor S, Richmond RH (2008) Gradients in coral reef communities exposed to muddy river discharge in Pohnpei, Micronesia. Estuar, Coast Shelf Sci 76:14–20

Golbuu Y, Wolanski E, Harrison P, Richmond RH, Victor S, Fabricius KE (2011) Effects of land use change on characteristics and dynamics of watershed discharges in Babeldoab, Palau. Micronesia J Mar Biol. doi:10.1155/2011/981273

Kayanne H, Omori M, Fabricius K, Verheij E, Colin P, Golbuu Y, Yukihira H (2007) Coral reefs of Palau. Palau International Coral Reef Center, Koror

Liston J (2009) Cultural chronology of earthworks in Palau, western Micronesia. Archaeol Ocean 44:56–73

Liston J (2011) Archaeological monitoring and emergency data recovery for the Compact Road, Babeldaob island, Republic of Palau. Historic preservation investigations, Phase III. Volume XII: lab analyses, discussion, syntheses. Prepared for the US Army Corps of Engineers, Pacific Ocean Division, Hawai'i. International Archaeological Research Institute, Inc., Honolulu

Liston J, Tuggle HD (2006) Prehistoric warfare in Palau. In: Arkush E, Allen MW (eds) The archaeology of warfare: prehistories of raiding and conquest. University Press of Florida, Gainesville, pp 148–183

Masse WB, Liston J, Carucci J, Athens JS (2006) Evaluating the effects of climate change on environment, resource depletion, and culture in the Palau Islands between AD 1,200 and 1,600. Quatern Int 151:106–132

McKnight R, Obak A (1960) Taro cultivation in Palau. Anthropological working papers, No. 6, Guam, p 1–47

Palau Society of Historians (2008) Stories with moral lessons. Bureau of Arts and Culture, Ministry of Community and Cultural Affairs, pp 1–60

Richmond RH, Rongo T, Golbuu Y, Victor S, Idechong N, Davis G, Kostka W, Neth L, Hamnett M, Wolanski E (2007) Watersheds and coral reefs: conservation science, policy and implementation. Bioscience 57:598–607

Toy TJ, Foster GR, Renard KG (2002) Soil erosion: processes, prediction, measurement, and control. John Wiley, Technology & Engineering

Victor S, Golbuu Y, Wolanski E, Richmond R (2004) Fine sediment trapping in two mangrove-fringed estuaries exposed to contrasting land-use intensity, Palau, Micronesia. Wetl Ecol Manag 12:277–283

Victor S, Neth N, Golbuu Y, Wolanski E, Richmond RH (2006) Sedimentation in mangroves and coral reefs in a wet tropical island, Pohnpei, Micronesia. Estuar Coast Shelf Sci 66:409–416