Wet Taro Cultivation on Atolls : A Techno-cultural Paradox?

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Irrigated Taro (Colocasia esculenta) *in the Indo-Pacific*
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Low islands are in themselves a natural paradox, each with a surface of a mere few square kilometres rising up to seven meters above the ocean, a basic soil made of coral debris scattered on calcified beach rock, no visible fresh water resources, and exceptional isolation. There was nothing, apparently, to inspire or support human settlement. The first European visitors, staggered by the aspect of these islands, imagined that the islanders were either the lost survivors of wreckage, or outcasts. Archaeological surveys in the Tuamotu atolls have revealed rather large and complex distributions of pits and trenches dug into the coral sand and pebble substratum. Oral traditions recorded in Tuamotu indicated that these structures were cultivation pits in which taro and other aroids were grown. Reconstruction of techniques and social structures associated with these basic food resources have been confirmed by observations from the Cook Islands to the atolls of Micronesia, especially Kiribati. Across these regions, special knowledge of how to use the natural resources of low islands was previously widespread. Undergound water, and the particular plants used for mulching, provided the moisture and nutrients needed for low island horticulture.

1. The Setting

Located in the eastern Pacific Ocean, the Tuamotu Archipelago is one of numerous atoll necklaces that are more-or-less grouped into archipelagoes, all along an arc that runs from the eastern Tuamotus to Insulinde. This arc follows an undersea line of ‘hot spots’ in the Pacific Plate.

Each atoll is composed of low islands, formed by the growth of coral on submerged volcanoes. The nearby high islands were also formed on volcanic foundations, but differ greatly in appearance, and are generally surrounded by fringing coral reefs. Over millions of years, the high islands have experienced uplift, erosion, subsidence, eustatic movement, and changes in sea level. They show greater topographic diversity than atoll formations.

Many geophysical surveys have been carried out in the Tuamotus describing their environment and remote situation. The group is comprised of 75 atolls with a total land-surface area of some 775 km^2. Rainfall is generally rather low, and varies from 1,500 to 2,500 mm per year, with occasional periods of heavy rain.

The possibilities for agriculture on atolls are naturally very limited. The original soil on each atoll was formed entirely from coral erosion debris, but supported nevertheless a natural vegetation cover of shrubs and some large tree patches (Mueller-Dombois and Fosberg 1998).

Cyclical changes in vegetation can be seen, even in the absence of human activities or extreme climatic stresses (hurricanes, tsunami, tropical gales and droughts) (Wiens 1962).

In our study area, early European navigators, traders and missionaries, from the 17th to 19th century, often described islands covered with a more-or-less dense and regular vegetation (see early sources in Appendix 1). Surprisingly, the islands were almost everywhere lacking coconut trees, in noticeable contrast with the general presence of coconut trees across the western tropical Pacific high islands.

2. Technical Knowledge and Survival

Human survival everywhere depends on food and water resources. On atolls, the presence of fresh water is not obvious. The flatness of ground does not permit the existence of any spring, and the only visible, surface locations with fresh water are more-or-less brackish and tend to be ephemeral, in places with natural shallow depressions, behind beaches or karstic calcified coral outcrops. Luckily, a large part of the rain falling on the surface of an atoll is trapped in an underground lens of fresh water that floats on top of sea water infiltrating the porous bedrock. There is no movement or interaction between the two fluid masses after rain has percolated through the upper layers of coral sand and debris. The rainwater gathers into a layer of fresh water that ranges between 20 cm and just under two metres in thickness. This accumulation of water has been called the Ghyben-Hertzberg lens, and it is also influenced by shorter- to longer-term changes in sea level and island height (Mueller-Dombois and Fosberg 1998: 409, 434; Nunn 1989).

On atolls, a basic knowledge of the water situation was absolutely necessary for any long-term settlement by new dwellers on such islands. Access to the hidden fresh water lens was provided by constructing wells for drinking and consumption water as well as by digging the cultivation pits down to the water lens (Figs. 1 and 2).

Such constructions can be found in every place where communities from the past until

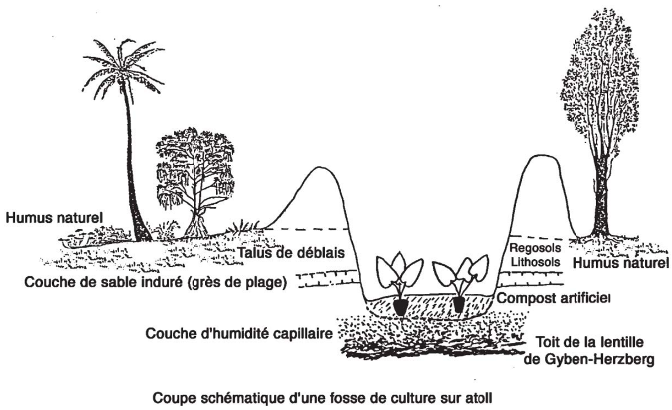

Figure 1 Schematic sketch of a cultivation pit on low island

Figure 2 View of a large area of cultivation pits on Tatakoto, Tuamotu

recent periods settled. The upper surface of the water lens is usually located at between 20 cm and 2–3 m below the ground surface. Above this lens, a layer of soil—up to 20–25 cm in thickness—is maintained in a wet, saturated state. The existence of the hidden fresh water lens is what islanders had to know, even before they landed on the low islands. Knowledge of this sort was of course usual in the Pacific-fringe and Oceanic cultures. It was part of a knowledge of everything linked to the sea, the lagoon, and the general possibilities for vegetable cultivation in tropical environments (Shutler and Marck 1975; Cox and Banack 1991). Such knowledge formed a large part of the Austronesian cultural heritage. If taro and other edible aroids were already important for settlers on atolls and other islands, finding and managing water to grow them was presumably a primary preoccupation when new islands were occupied.

Evidence for detailed local knowledge of fresh water can be seen from the smallest islets (less than 5,000 sq m.) of the Tuamotus (Chazine 1985) to the easternmost shores of Borneo, and through the Solomon Islands, as well as in Micronesia and the islands of the Indo-Malaysian region. When the elements necessary for survival are brought together, i.e. water in sufficient quantities for at least a minimum-sized community, and plants suited to atoll environments, then knowledge and agrarian techniques can be employed to produce the necessary food. To reduce the difficulty, indeed near-impossibility, of cultivating infertile and dry surface soils, islanders dug holes (pits or trenches) down to the wet layer situated just above the water lens, then re-introduced the original upper soil and even upgraded it by creating an artificial mulch.

This first step is itself a clever enhancement of the natural possibilities of the existing environment, but is limited by the very thin natural layer of black topsoil (just a few centimetres). To build up soil for cultivation, islanders invented—or re-invented and adapted locally—the mulching process. Through mulching, the production capacity of these totally

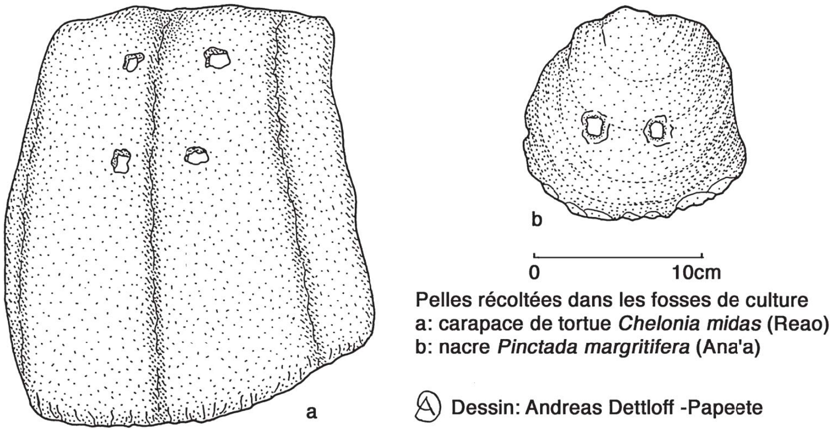

Figure 3 Examples of shovels: (a) turtle-bone, (b) mother-pearl shell

artificial gardens, was greatly enhanced.

In our surveys (Chazine 1977, 1985, and Appendix 1) we found that the atoll surfaces dug to excavate holes for gardens ranged in total area from 100 to more than 10,000 sq m., figures that can be contrasted with total atoll surface areas of 3 to 30 or more sq. kms. The depth of holes was rarely less than 1 m and often reached 1.5 or 2 m, even breaching in some places a layer of hard beach rock itself. Considering both depth and area allows calculation of the quantity of excavated volumes, the spoil produced, and thus the quantity of work that was necessary to make atoll landscapes productive.

The usual tools for digging were very simple, consisting of turtle bone plastrons and mother-of-pearl shell shovels mounted on wooden hafts (Fig. 3). With such tools, no single individual could remove hundreds of cubic meters of sand or other materials. Diggings often went through stony layers, and sometimes the splitting and extraction of thick beach rock layers was required. Natural concrete is often formed by the dissolving of calcium from coral, followed by precipitation as calcite at the fluctuating interface of fresh and salt waters. Ethnographic data indicate that the equivalent of at least one month of work by one person was necessary to dig a single medium (5×6 m or 10×3 m) pit with turtle or shell shovels. Archaeological examples of the latter artefact type have been found in different cultivation pits in Tuamotu.

Communal organization and effort were surely needed for long-term development and management of the islands. Surface surveys conducted on the Tuamotu and Kiribati atolls (see map, Preface, this volume) have provided comparative and complementary data on pit dimensions. The mean values were similar, but the minimum surface area of a pit garden was about 12 sq. m., while the mean and most common (median) values were around 30 sq. m. The overall surface areas involved in agricultural activity are most impressive when we consider both the areas dug and the areas covered with excavated materials. The general aspect of the occupied islands is very different from the usual flat appearance of atoll islands in their natural state. The term "horticultural" has often been used to describe Oceanic

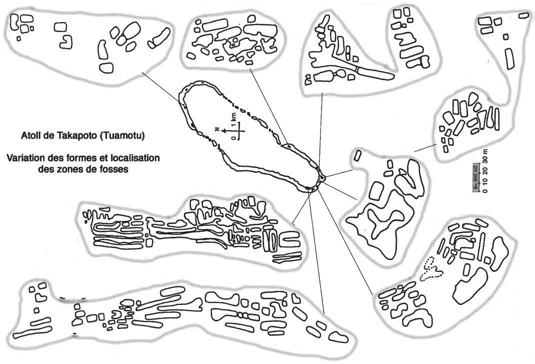

Figure 4 Variation in pit shapes, and location of taro pits patches on Takapoto atoll, Tuamotu

communities (Shutler and Marck 1975), but this deliberate and extensive modification and reconstruction of soils goes beyond what is usually considered horticultural.

Enquiries across different atoll archipelagoes have confirmed that private property was unknown in ancient pre-European communities, so rights to land were managed and distributed by assemblies of elders. Rights were allocated for the life of the recipient, and required continued presence to remain valid. Thus sizes and shapes of garden pits vary from one place to another. This variation has not been fully deciphered but presumably depended upon the size of the associated community, the quality of the natural soil, and the history of settlement. This would follow the common Polynesian practice where common or exceptional events are re-historicised and linked to the mythic origin of the community, wherever it originated (Taonui 2006). Historical processes of settlement and extension can be approached by surveying ceremonial structuress such as *marae* that generally lie in the vicinity of settlement areas.

Groups of pits, numerous individualized pits with formal shapes and large, expanded pits with non-formal shapes (Fig. 4) may reflect chronological changes from complex to simpler levels of communal organization for survival on low islands. When the larger cultivation pits (as they are commonly called) were made, they suddenly transformed the flat atoll landscape into “Russian hills” that spread over hectares, reaching heights of 8 m. Mounds of such height may have had significant practical value as places of shelter or refuge during storms and tsunami—this has been mentioned by present-day island inhabitants in relation to the late 1983 hurricanes. They form patches with a minimum of two units to more than 100 units in some cases. The mean numbers range from 6 to 10 or 12, then 20, 40 and 60 on some atolls.

Ethnographic data have been compiled from interviews with inhabitants, and from eyewitness accounts, on low islands across the Pacific. These confirm the detailed information collected or observed by the first pioneering scholars in the 1950 to 1960s (Massal and Barrau 1956; Barrau 1961; Wiens 1962; and the *Atoll Research Bulletin* articles in particular). These indicate that at least two pits should be dug initially to be later worked alternately. While one is in production, the second, once fallowed, has its fertility regenerated. Growing periods usually range from 9 to 14 months, depending on the cultigens used, and climatic conditions.

From Tuamotuan and Cook Islands' low islands informants, *Colocasia* (and *Alocasia*, at a lesser scale), planting densities in these gardens (e.g., shoots on a 40 cm grid, over an area of 30 sq. m) can provide more than 150 tubers each 8 to 14 months. With clonal reproduction and multiplication, each parent shoot can produce 1 to 3 shoots, for replanting in a newly regenerated pit. In Kiribati and other areas using mainly *Cyrtosperma*, the spacing as well as the planting process differ. Using vegetal pots or baskets which may be removed, they need more space and the distance between plants may reach 1 m as the size of the leaves grows.

The bottom soils of cultivation pits (and large trenches) are regenerated in the same way as at first preparation: small branches and leaves of selected shrubs and trees are chopped into small pieces, and are then mixed with black sand or soil collected from inside or outside the pit itself. The main plants used for mulch have been empirically selected from the local natural flora: *Guettarda*, *Messerschmidtia*, *Pisonia* and *Scaevola*. *Pisonia* appears to be the most effective component because it fixes more nitrogen than other species. The naturally compost-enriched soil at the foot of these trees is further enriched by birds nesting in the branches and leaving guano rich in phosphates.

Although the general process of preparing an artificial compost seems to have been employed everywhere on low islands, the specific methods vary locally. Among the eastern archipelagos (Tuamotu and Cook islands) mulch is laid over the whole bottom surface, while in western Kiribati single baskets are filled with compost and placed in pits to provide new soil for individual plants. This individualization corresponds practically to socially-important events like weddings or births, when a large amount of food has to be provided for feasts.

Variation in personal skills and attention is also important. Competition between individuals and/or families can stimulate people to elaborate new and more productive methods. In Kiribati the biggest corm of swamp taro (*Cyrtosperma merkusii*; syn. *C. chamissonis*) may win a prize and prestige for its grower. In some cases the crop is kept in the ground for two years before a specific scheduled event such as a wedding. In the absence of witnesses, we don't know if similar competition existed in pre-contact Tuamotu, but it seems likely. On Ana'a Atoll in Tuamotu, we succeeded in re-activating archaeological cultivation pits, and one year later organized an Agricultural Show to display the results. The competition between families and lineages emerged immediately, and led to an unexpectedly large quantity of corms and stems (*Colocasia* and *Alocasia*), and greater production of many other vegetables and fruits (*Cordyline*, lemons, limes, bananas, sugarcane and arrowroot)—crops that were supposed to have almost totally vanished from the island.

Sunken gardens are mainly evident in Tuamotu in the archaeological remains of cultivation pits, but the practices, knowledge and technology involved to make and manage such gardens are still alive in most of the western Pacific—albeit threatened by modern techno-economic constraints. Their existence, past and present, depends on knowledge of two basic resources: the underground lens of fresh water, and the mulch that can be obtained from local vegetation to enhance the structure and fertility of naturally-poor soils.

The water lens is particularly fragile because it is thin, and requires sensitive management. The unconscious breaching of that lens explains why for many foreigners the water on atolls has been—and very often still is—considered brackish! All the crop species used are known throughout most of Oceania, so differences in the knowledge of crops does not explain differences in the production systems of high and low island dwellers. The extremely limited water and fertility of atolls explains most differences.

The wet cultivation of *Colocasia* and its related genera in pits dug on atolls is an application of a general technique used on high islands, only differentiated by the presence or absence of running fresh water. As far as could be learned in the Tuamotus, the people could not easily get a large range of cultigens, so they dug secondary pits at greater or lesser depths where they could move the plants, depending of the incidence of rain or drought.

The slopes of the mounds created by the digging of the pits or trenches, were used for planting breadfruit, sugarcane, *Cordyline*, and the like. We were told that as soon as possible *Pandanus* shoots were encouraged to grow to provide edible drupes, fibrous roots, shade and to form protective fences. The flat sandy areas surrounding the pits were propitious for arrowroot's semi-natural growth. As far as we could learn agricultural consumption of the water lens never exceeded its capacity (unlike recent tourist hotels, unconscious of the natural limits of that water reserve!). From the numerous sketches mapping semi-archaeological cultivation pits distribution on Tuamotuan atolls compared to contemporary distribution in Kiribati, we may infer that extended family hamlets were located nearby or within the staple food production areas. Dwelling places are usually closer to the cultivation pits than ceremonial places like *marae* which would be used in common with neighbours.

It has also been observed that the importance of the water lens was dependent on the local micro-geology, i.e. the slope of the beach rock layer, which more or less retains the rain flux. Therefore, the atoll dwellers were obliged to follow the level of humidity of their plantations, moving their crops from one pit to another or from one level to another. This latter process would explain why in some pits in the Tuamotus, the bottom of the pits may suddenly vary by some 15 to 25 cm. These adaptive technical choices would have—extreme conditions like hurricanes or centennial rains or droughts apart—ensured stability in low island food production, in contrast to the uplands of high islands where heavy rains and landslides often destroyed terrace walls and water channels.

3. The Techno-Cultural Paradox

We are now ready to revisit questions concerning the origins of low-island settlers. Who were they originally, and where did they come from? For French Polynesia, the most obvious historical explanation is that the Tuamotu inhabitants came from high islands as refugees, escaping slaves or outcast commoners who previously belonged to Pomare's dynasty established in the end of 18^{th} century (Moerenhout 1942). This is supported by some oral traditions collected and perhaps elaborated, in the 19^{th} century.

This explanation does not fully recognise the basic fact that any long-term survival on an atoll is based on knowledge of the hidden water supply and how to manage it. How was such technical knowledge first acquired? High island occupants did not need to know that there is a sunken and hidden fresh water lens on atolls.

Mulching is more generally known, as part of the common "horticultural" tradition of Austronesian speaking societies assisting the growth of fruit trees, but knowledge of the specific qualities of plants used for the most effective mulching might not have been part of the general experience of most high island dwellers—at least not for those at the eastern end of the Pacific migration, when the Society, Marquesas and Austral islands were reached.

Human settlement on tiny, ecologically unstable, and physically unprotected atolls can be precarious, and extreme events such as hurricanes make long-term settlement appear tenuous at best. The strikingly high death toll on atolls during hurricanes in 1878 and in the period 1903–1906 was in large part due to the socio-economic reorganisation of settlements and mother-of-pearl diving activities on atolls. Extreme susceptibility to hurricanes only became noticeable after traditional organization was disrupted or destroyed after the middle of the 19th century, as a result of the introduction of coconut monoculture and the beginning of a colonial plantation economy. The new social order led directly to the abandonment of cultivation pits and the associated mounds that provided protection and refuge from high waves.

The people who first landed and settled atolls in the eastern Pacific were not necessarily originally from high islands. They may have come directly from atolls in the central Pacific, bringing with them the knowledge, materials, experience and courage needed to survive on such limited bits of earth. If people with knowledge of how to live on atolls were the first migrants to the eastern Pacific (as suggested by Marck and others – eds), then that knowledge may have been lost over time as unnecessary on high islands, after those too were settled.

The techno-cultural paradox mentioned in the title of this paper refers then to the question of how people could survive in such places long enough to acquire the knowledge and materials needed to remain there. This paradox applies to wherever people without previous atoll experience first tried to settle atolls. Observations from the northwestern Pacific area are likely to provide clues regarding the ultimate origins of low island settlers (*cf.* Kirch 2000).

Another paradox relates to wider historical questions. Although the origin of the Polynesians now begins to be understood, the immediate origins of low island settlements, especially in the far eastern Tuamotus, remain largely unknown. Understanding the low islands better has potential to provide a key to understanding the origins of high island settlement in that region as well.

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