5

The Wetland Field Systems of the New Guinea Highlands

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Introduction

This chapter provides an ethnographic and historical overview of the various traditional practices of wetland drainage and wetland field systems documented across the New Guinea highlands during the period since initial contact with colonial administrations in the 1920s and 1930s. The distribution and hydrological settings of these wetland drainage systems are mapped, differences in the technologies of drainage and wetland gardening are described, and the varying social contexts that create the demands for their use are addressed. The chapter concludes with some consideration of the genesis of these historical or ethnographic wetland field systems: are they the outcome of independent processes of invention and modification in different highlands locations or is there evidence that knowledge of wetland drainage techniques might have diffused from a single location or a limited number of centres within the region, or even from the New Guinea lowlands or coast? And, in the context of the Kuk Swamp finds, might these ethnographic examples offer possible analogues for the more recent phases (5 and 6) of the archaeological sequence of the Wahgi wetland drainage systems?

There has been a surprising paucity of ethnographic research into wetland field systems in New Guinea, and very little comparison drawn between different systems. While detailed accounts exist for wetland gardening practices in a few locations, they tend to be treated individually. This chapter is a first attempt at a systematic review of the different wetland drainage systems of the highlands. The term 'drainage' is used here as shorthand for water management practices more generally, ranging from true drainage through to irrigation. The advantages conferred by drainage and other water management practices include greater control over environmental factors, a higher crop yield per hectare than comparable dryland systems and increased potential for further intensification (Spriggs 1990). Drainage 'systems' are composed of contiguous fields where some degree of cooperative activity beyond the simple construction of an individual plot is responsible for the creation of a network of linked plots or fields.

Figure 5.1 Distribution of wetland management systems across New Guinea.

Source: Karina Pelling, CartoGIS Services, College of Asia and the Pacific, ANU.

The field systems on which this chapter focuses are all located in the central highlands of New Guinea; Figure 5.1 shows locations across the main island of New Guinea referred to here, while Figure 5.2 provides more detail on locations within the highlands region of Papua New Guinea (PNG). The distribution of drainage as an agricultural technique across PNG has been mapped by The Australian National University's Mapping Agricultural Systems Project (Allen et al. 1995), which demonstrated the fairly tight restriction to the highlands region of drainage as an important technique within local systems (Fig. 5.3). Smaller and more localised drainage systems are also found in the New Guinea lowlands—most notably on the south coast between the Fly River and Digul River estuaries and on Kulepom Island in west New Guinea (Serpenti 1965; Harris and Laba 1982; Barham and Harris 1985; Manembu 1995; Harris 1995; Hitchcock 1996) and on the Amogu floodplains in the middle Sepik area (Allen 2005: 613; Swadling and Hide 2005: 315)—as well as in some of the neighbouring regions of eastern Indonesia and Island Melanesia (see the overviews by Damm 1951 and Spriggs 1990). However, there are no obvious connections between these systems and those of the highlands in terms of crops, techniques or methods of production. Similarly, no further consideration is given to irrigation techniques practised in moisture-deficient locations, as at Dogura in Milne Bay Province (Kahn 1985, 1986) and in the Lamari Valley (Loving 1976), both of which involve the long-distance transport of water by bamboo aqueducts (see Gorecki 1979a for notices of small-scale taro irrigation in the highlands). This chapter also focuses on water management for agricultural production rather than damming for fish or eel production (Dosedla 1984: 1130–1131) or for purely ritual or ceremonial purposes, as in the case of the dams of the Huon Peninsula (Vial 1938; Holzkecht 1998).

Figure 5.2 Distribution of wetland management systems in the highlands of PNG.

Source: Karina Pelling, CartoGIS Services, College of Asia and the Pacific, ANU.

The highlands focus of this review evidently presumes some degree of relationship amongst the different highlands wetland field systems, but the argument made here is that this relationship holds only at the widest level of cultural and technological relatedness. What the wetland field systems of the highlands appear to share, beyond the constraints of a suite of similar local environmental conditions, is a common crop repertory, a limited range of agricultural technologies and broadly parallel demands on production, particularly in relation to the raising and exchange of pigs as items of wealth and transaction. In the place of any evidence for diffusion of a single wetland field system, as a set of techniques and cultural contexts, we find a process that might be described as broadly common throughout the highlands: early field systems, which are developed initially along the highly productive and partially clear margins of swamps, are subsequently extended both into swamp centres and up onto adjacent dryland slopes.

Figure 5.3 Distribution of drainage as an agricultural technique across PNG.

Source: Bourke and Allen (2009: 261, Fig. 3.12.1), courtesy of the Land Management Group, Department of Human Geography, ANU.

Swamp hydrology and catchments

In order to appreciate the nature of any particular wetland field system, the specific context of its hydrological conditions must first be determined, along with the constraints and opportunities that these conditions present for wetland use. For the purposes of this chapter, wetlands are defined as essentially a human artefact, referring to a modified intermediate zone between natural dryland and unreclaimed swampland (Gorecki 1982: 223). The boundary between dryland and swampland represents a critical margin, usually marked by a sharp vegetation break. With minimal additional investments of labour, gardeners in this marginal zone gain access to an exceptionally productive environment, which also serves as a moisture reservoir during seasonal or exceptional dry periods. As demands on agricultural production increase, wetlands can be expanded, usually involving incrementally higher inputs of labour as the wetter areas of swampland are reclaimed.

Most highlands swamps are created by natural impediments to natural drainage, such as tectonic uplift or landslip processes (Chambers 1987: 6). Though there are more elaborate schemes (e.g. Ingram 1983), most of the swamps can be classified as either perfluent, low-lying areas around a major watercourse that are prone to flooding, or lake-margins, where the scope for drainage tends to be restricted by the presence of a static body of open water. The hydrology of individual swamps may be altered over time either by natural processes, such as earthquakes or the gradual erosion or removal of the impediments generating the swamp, or by human intervention, such as drainage or clearance in the catchment and a consequent increase in sedimentation.

Figure 5.4 Swamps and catchment areas in the Tari region.

Source: Karina Pelling, CartoGIS Services, College of Asia and the Pacific, ANU.

Significantly, human drainage initiates changes in hydrological regimes that can ultimately undermine the wetland field systems that it seeks to enable. Shrinkage of swamp peats following drainage can lower the swamp surface dramatically and render the initial drainage channels ineffective (Hartley 1967; McGrigor 1973). At the same time, increases in dryland clearance can exacerbate the scope for flooding in low-lying wetlands; under different conditions, increased clearance can result either in the scouring and destruction of drains by higher-velocity flow or the silting up of channels with excessive sediment loads.

Comparison of a 'nested' series of catchments and drained wetlands in the Tari region reveals some of the complex relationships governing the hydrology and scope for drainage of highlands swamps (Ballard 1995, 2001). A 'cascade' effect, in which water from higher catchments flows through to lower and larger catchments, directly influences the variable scope for wetland drainage at individual swamps. Contrary to expectations based on population pressure, the central parts of the largest swamp, Haeapugua, which lies closest to the historic centre and highest density area of the local Huli population in the Tari Basin, appear to have been drained later than the more distant swamps of Mogoropugua and Dalipugua, which have far smaller catchments, but feed one into the other and then both into the Haeapugua catchment (Fig. 5.4). The ratio of swamp to catchment areas, which yields a coefficient of dryness for the individual swamps (Table 5.1), indicates the highly variable scope for drainage of the different swamp areas, with Haeapugua revealed as a much wetter and more challenging environment for drainage. However, it is argued that one consequence of the adoption of sweet potato was the migration of large numbers of people into the uplands of the Tagali River catchment and the rapid clearance and degradation of this fragile environment. A further, inadvertent consequence of the dramatic increase in soil erosion in the upper reaches of the catchment was the generation of sufficient sediment to finally stabilise the levee banks of the Tagali River where it flows through Haeapugua Swamp (Fig. 5.5), thus rendering the swamp centre available for drainage. Evidently, hydrological conditions at individual wetlands need to be determined, and to be considered within the context of entire catchment areas, before arguments about population density or demands on agricultural production can be entertained.

Figure 5.5 The Haeapugua Swamp wetland field system.

Source: Karina Pelling, CartoGIS Services, College of Asia and the Pacific, ANU.

Table 5.1 Catchment/swamp area ratios for swamps in the Tari region.

Swamp	Elevation (metres)	Catchment area (km ²) [C]	Swamp area (km ²) [S]	Catchment/swamp ratio [C/S]
Lebani	2250	143.83	7.77	18.5
Mogoropugua	1870	63.58	7.60	8.4
North	1870	24.28	4.11	5.9
South	1870	38.69	2.87	13.5
Wabupugua (Yaluba Basin)	1790	63.91	1.32	48.5
Dalipugua (Koroba Basin)	1700	231.44	6.97	33.2
Haeapugua	1650	1075.99	17.10	62.9
Urupupugua (Tari Basin)	1610	5.11	3.32	1.5

Source: Ballard (2001: Table 2).

Distribution of wetland field systems

The distribution of wetland drainage in the highlands suggests that demands on production from relatively dense populations play a critical role in the decision to commit resources to the creation of drained field systems. The upper limit to taro-based or pre-Ipomoean agriculture in the New Guinea highlands is between about 2200 m and 2400 m (see Chapter 4). The adoption of sweet potato has extended this range to about 2700 m, but population densities tend to decline markedly above about 2200 m; a few communities reside and have drained swamps at higher altitudes, such as the Yumbisa Valley in western Enga at 2550 m (Wohlt 1978). At the lower end of the highlands range, an altitude of about 1300 m commonly marks the upper limit of endemic malaria, which tends to curb population growth. Almost all of the documented drained wetlands in the highlands fall within the altitudinal range from 1300 m to 2200 m. There is little evidence to suggest that available wetlands in settled areas below 1300 m, such as those around Lake Kutubu at 800 m, have been drained in the recent past. The one major exception is the Samberigi Valley of Southern Highlands Province, at 980 m, where extensive drainage networks were described in the 1920s but not in further detail since (Beaver 1920: 262; Saunders 1923–24: 29; Bourke et al. 2002: 100).

A survey of the major wetland field systems of the highlands suggests that most of the major accessible swamps within the 1300–2200 m altitudinal band have been exploited. These major wetland field systems are listed in Table 5.2, along with the principal documentary sources for each system, and their distribution is mapped in Figures 5.1 and 5.2. In the western half of New Guinea, the two major areas of highlands swamp—in the Paniai region comprising the Paniai Lakes Basin and the adjacent Kamu Valley, and the Grand Valley of the Baliem River—have both been drained and heavily utilised; no other extensive wetland field systems are known from western New Guinea (Ploeg 2005). A large gap in distribution is accounted for in part by the absence of major intermontane basins between the Grand Baliem Valley and the Strickland Valley. Raised-bed cultivation of sweet potato, with use of the mud and mulch from the interbed drains or hollows similar to techniques employed in the Grand Baliem Valley, is practised by Mek-speakers of the Eipomek Valley (Röll and Zimmerman 1979: 19ff; Michel 1983: 59, Figs 52, 53), though the valley's steep topography does not allow for the development of wetlands. However, from the Strickland Valley to the eastern highlands of PNG, most of the major valleys contain swamp areas and the majority of these have been drained in the recent or prehistoric past.

There has been no comprehensive review of highlands swamps and their use that might allow us to determine precisely the proportion of swamps that have remained unexploited agriculturally and to plot their distribution. The only significant examples for which there is currently no ethnographic or archaeological evidence for intensive use are some of the smaller wetlands of the eastern highlands of PNG, but this apparent anomaly may reflect a lack of archaeological enquiry, as digging sticks have recently been recovered from a small wetland area in the Asaro Valley (Tim Denham, pers. comm., 2008). Swamps in the Kainantu region, at the very eastern end of the central highlands, appear to have been used only at their margins, if at all, prior to colonial administrative contact (Schindler 1952; Grossman 1984; Bourke 1992; Haberle 1996). The marked seasonality and dry periods experienced in the eastern highlands (see Chapter 4; see also Bryan and Shearman 2008: 111, Fig. 64) might be expected to have rendered wetland use even more attractive than at other locations. However, it is possible that a strong cultural commitment to existing seasonal crop repertoires, and especially the cultivation of yam during dry periods, may have militated against more extensive wetland drainage. Grossman (1984: 153–154) also records strongly held fears of swamplands amongst eastern highlanders at Barabuna, which appear to have operated as a brake on wetland use.

Table 5.2 Wetland agricultural systems of the New Guinea highlands.

Region	Locale	Ethnic community	Altitude (masl)	Principal sources
Paniai region	Paniai Lakes Basin	Me	1640–1740	Le Roux 1948–50; Barrau 1955; Pospisil 1963; Ploeg 2000
	Kamu Valley	Me	1500	Pospisil 1963
Grand Valley, Baliem River		Grand Valley Dani	1400–1500	Brass 1941; Heider 1970, 1997; Soenarto 1987; Schneider et al. 1993; Purwanto 1997; Soenarto and Rumawas 1997
Tari region	Lake Kopiago	Duna	1320	Robinson 1999
	Haeapugua	Huli	1650	Powell with Harrison 1982; Wood 1984; Ballard 1995, 2001
	Dalipugua	Huli	1700	Ballard 1995
	Mogoropugua	Huli	1870	Ballard 1995
North Mendi, Western Enga, Kaugel	Upper Mendi Valley	North Mendi	1950	Mearns 1986
	Marient Basin	Enga-North Mendi	2420	Clarke 1989
	Kandepe Basin	West Enga	2340	Wohlt 1986
	Yumbisa	West Enga	2550	Wohlt 1978
	Upper Kaugel Valley	Kakoli	2100–2200	Bowers 1968; Bayliss-Smith 1985a
	Wahgi Valley	Melpa	1580	Vicedom and Tischner 1943–48; Powell et al. 1975; Gorecki 1982;
Eastern highlands	Aiyura	Gadsup	1600	Schindler 1952; Bourke 1992
	Norikori Swamp	Tairora	1750	Haberle 1996
	Barabuna	Tairora	1670	Grossman 1984

Source: Data collated by Ballard.

Technologies of wetland drainage

Given environmental conditions that might allow for wetland drainage, the development and particular form of individual drained field systems tend to reflect several additional factors, including available techniques, crop suites and their requirements, local demands on production and the social organisation of production.

The technologies of highlands wetland field systems are not markedly different in most respects from those used on drylands adjacent to swamps. Significantly, there is no evidence for wetland agriculture without a dryland counterpart. Technologies developed on the dryland margins of swamps are extended both to the surrounding dryland slopes and to the wetter swamplands. This dryland marginal context for wetland technology is physically evident in the form of wetland drains, field systems and digging implements.

Wetland drains

Across the highlands, wetland drains represent a deepening and widening of adjacent dryland margin ditches. Thus the narrow and shallow ditches of the Grand Baliem Valley dryland *wen alobaga* gardens, typically 0.5–0.75 m wide and 0.5–1.0 m deep, are substantially expanded as drains for the wetland *wen imah* gardens, which range from 1.0–2.5 m in width and 1.5–2.0 m in depth (Purwanto 2004). There is considerable variation in wetland drain dimensions within and between individual highlands field systems, reflecting local hydrological conditions, but drains are commonly 1.0–3.0 m wide and 0.5–2.0 m deep (see Table 5.3). The exceptional depths

recorded for drains in the Tari region reflect the fact that ditches in this area extend uninterrupted from dryland slopes through wetland margins and into the swamp centres. On dryland in the Tari region (where their function is primarily related to land boundary marking, defence and keeping pigs out of gardens), ditches up to 4 m in depth are not uncommon, generating a dense grid of irregular form laid over much of the inhabited and cultivated landscape.

Table 5.3 Wetland drain dimensions.

Location	Drain width (m)	Drain depth (m)
Paniai region	n.a.	0.5–1.0
Grand Baliem Valley	1.0–3.0 (major drains 5.0)	0.6–2.0
Tari major drains	2.0–5.0	2.0–3.0
Tari minor drains	1.0	1.0–1.4
Marient	n.a.	Up to 2.0
Upper Wahgi	1.0–1.5	0.6–1.6
Barabuna (eastern highlands)	1.2–2.0	0.9–1.3

Source: See Table 5.2 for sources from which the data were taken.

Figure 5.6 Drain hierarchy at Haeapugua Swamp, Tari region.

Source: Karina Pelling, CartoGIS Services, College of Asia and the Pacific, ANU.

In the more elaborate wetland field systems, a hierarchy of drain sizes and functions can be discerned and is often identified and named in local language. Dani people of the Grand Baliem Valley have developed a wide range of terms for the different elements of their intricate and highly variable field systems and discriminate between smaller drains (*ikala*) and the larger drains that enclose a family group's garden beds (*wen panla*) (Purwanto 1997: 355–356). In the Tari region, Huli people distinguish between small ditches within individual garden blocks (*de gana*), deeper drains surrounding garden blocks (*gana*) and the largest drains (*iba puni*), into which empty the *gana* drains of an entire clan or subclan territory (Fig. 5.6).

Wetland field systems

Wetland field systems range in scale from isolated individual plots, such as the taro gardens in boggy sinkhole depressions of the Nembi Plateau (Sillitoe 1996: 187) or the cultivated drainage depressions of the Kainantu region (Bourke 1992), through to networks such as those of the Grand Baliem Valley or the Tari region that encompass the gardens of multiple clans. Very few field systems have been mapped beyond the level of individual gardens; extensive maps that allow for detailed comparison are available only for Lake Kapiago (Robinson 1999), Haeapugua Swamp in the Tari region (Ballard 1995; Fig. 5.5 here), Yumbisa Valley in western Enga (Wohlt 1978), the upper Kaugel Valley (Bayliss-Smith 1985a; Fig. 5.7 here) and the reconstructed field systems for archaeological Phases 5 and 6 at Kuk Swamp (Bayliss-Smith et al. 2005). All of these mapped field systems conform broadly to the rectilinear, coaxial pattern illustrated for Haeapugua Swamp in Figures 5.5 and 5.8.

Figure 5.7 Drainage system for mixed taro gardens at Kiripia, upper Kaugel Valley.

Source: Karina Pelling, CartoGIS Services, College of Asia and the Pacific, ANU.

Figure 5.8 Aerial photograph of wetland field systems, Haeapugua Swamp, 1978.

Source: Mapmakers Pty Ltd, reproduced with permission.

On this admittedly slender basis, a number of features common to highlands wetland field systems can be proposed. Brookfield and Brown (1963: 44–45) have suggested that drainage grids ‘tighten’ with increasing moisture, but this is an observation made from the perspective of dryland field systems, where individual field sizes are generally larger than those on swamp margins, which require a closer network of drains. As wetland field systems extend into swamp centres, the fields actually grow larger in area again, reflecting their shorter lifespan and a more limited commitment to maintaining drainage in an environment so exposed to flooding (for data on contrasting field sizes in different parts of Kuk Swamp, see Bayliss-Smith et al. 2005: Table 3). This is clearly illustrated in the map of the Haeapugua Swamp field system (Fig. 5.5), where those fields closest to the swamp’s centre near the main Tagali River are also the largest in area.

Another general observation is that increasing moisture tends to be associated with an increase in the regularity and linearity of drain networks. This presumably reflects both the hydrological advantages of removing excess water as efficiently as possible via straight drains and the scope for conformity in the plan and layout of a pioneering field system in a flat and newly colonised space. The one challenge to this generalisation comes from the convoluted form and seemingly infinite variety of the field systems of the Grand Baliem Valley, of which examples are shown in Figures 5.9 and 5.10. The hydrology of the Grand Baliem Valley remains poorly documented, however, as do its field systems, and it seems probable that the reticulate form of local drains is designed to trap and manage occasional overbank flows from tributaries of the Baliem River; it would be interesting to determine whether the flood-prone field systems closer to the Baliem River are more linear in their layout.

Figure 5.9 Dani terms for components of the field system in the Grand Valley of the Baliem River.

Source: Karina Pelling, CartoGIS Services, College of Asia and the Pacific, ANU.

Figure 5.10 Aerial photograph of Dani wetland field systems, Grand Valley, 1987.

Source: Photograph by Chris Ballard.

Local convention certainly plays some role in the variability evident amongst different wetland field systems, most obviously in the case of the Dani elaboration of forms in the Grand Baliem Valley, but also amongst Huli of the Tari region, where there is a commitment to ditches and drains that far exceeds the needs of water management. A particular Huli aesthetic is brought to bear on the construction of drains and the symmetry and smoothness of drain walls are subject to public appraisal; Huli initiates were formerly shown model landscapes, carefully crafted in mud, which served to display an ideal harmony in the layout of field systems and the locations of different house forms (Ballard, fieldnotes, 1990). There is also evidence from several locations of an enduring conservatism in field systems, as successive generations of drain excavators seek out the lines of earlier drains and reexcavate them in conscious imitation of known ancestors, identified by name as the first to have dug a particular drain (e.g. Ballard 1995: 96; see also Purwanto 1997: 358 on similar Dani practices). Although there is often considerable labour involved in removing the sloppy fill of an old drain, there is at least the certainty that the drain has functioned in the past and that the same claims to land are being activated (Fig. 5.11). At Kuk Swamp, archaeological Phase 6 drains appear to replicate the Phase 5 network, suggesting the observance of a similar practice in the recent past (Bayliss-Smith et al. 2005: 114).

Figure 5.11 Clearing a major channel at Haeapugua Swamp with traditional wooden rakes, 1991.

Source: Photograph by Chris Ballard.

The larger wetland drains serve a range of functions in addition to their role in the management of water: as a wetland equivalent of dryland garden fences, to keep pigs out of garden blocks; as roadways for both people and pigs; as social boundaries from the level of individuals through to clans; as boundaries between secular and sacred space; as temporal markers of local history and proofs of land ownership; and as defensive barriers during warfare (Williams 1940: 44; Ballard 1995: 95–98). Most drains serve many of these functions simultaneously.

Close attention to the layout of wetland field systems can also disclose the traces of earlier networks that allow for the reconstruction of relatively recent historical sequences of network development. At Haeapugua two different forms of earlier field systems are evident. The first consists of remnants of ‘covert’ drains within the existing wetland field system, aligned along different axes that have since been largely effaced (Fig. 5.12). The second, earlier field system is ‘fossilised’ along the wetland/dryland margins, where drains identified with some of the earliest clan ancestors (many of them now enclosing ritual spaces) take a more circular or ‘lobate’ form, composed of clusters of incomplete oval or lobate fields developed around even earlier oval fields (Fig. 5.12). It would be wrong, however, to draw the conclusion that lobate field forms necessarily precede rectilinear forms or that rectilinear field forms represent in themselves a particular developmental stage in the history of highlands agriculture. Rather the lobate fields resemble those employed by pioneer gardeners operating in a forested environment and less even topography, while the rectilinear forms are largely necessitated by the dictates of local hydrological conditions as gardeners push further into the swamp.

Figure 5.12 Early lobate field forms and fossil field systems at Haeapugua Swamp, Tari region.

Source: Karina Pelling, CartoGIS Services, College of Asia and the Pacific, ANU.

Digging implements

The repertoire of wooden implements employed in wetland drainage and agriculture at the time of colonial contact was fairly uniform across the highlands region (Powell 1970a: 35–36; 1974; Gorecki 1978; Steensberg 1980: 71–100; Golson and Steensberg 1985), with only a few local specialisations evident. Certain tools appear to be unique to specific locations, such as the *ma habono* taro-dibbling club of the Tari region (Ballard 1995: Table B12) or the *patau* ‘earth-knife’ of the Paniai region (Le Roux 1948–50, vol. 1: 290–291; Pospisil 1963: 105), which seems to have served many of the functions of the wider range of digging sticks and spades found elsewhere.

Golson (1977a: 629–630) has argued that the long-handled spades (with single or double spade-ends) used to cut fresh drain faces from a standing position above the drain wall and also to lift fertilising material up from the base of a drain, may have been developed initially in the context of swamp agriculture before being applied to dryland gardens (see also Golson and Steensberg

1985: 350–353, 360–361; Gorecki 1985: 342). Following the general argument of this chapter, an alternative way of framing this hypothesis would be in terms of a wetland technology suited to the swampland/dryland margin and capable of application to both swampland reclamation and dryland cultivation. Agricultural tools are discussed in further detail in the context of the Kuk investigations in Chapter 19.

Wetland crops and garden sequences

Within the altitudinal range of highlands agriculture, and subject to the individual limitations of particular crops (as outlined in Chapter 4), the suite of crops cultivated in wetland gardens varies little throughout the highlands region. Sweet potato now totally dominates the crop repertoire, by every measure. In pre-Ipomoean times, it is presumed by archaeologists (and assumed by many highlands people) that taro played a similar if slightly reduced role.

The contemporary garden sequence at Haeapugua Swamp, which may be taken as broadly representative of wetland sequences elsewhere in the highlands, opens with drain excavation or clearance, followed by a period of up to two years during which the area is allowed to drain (Powell with Harrison 1982). An initial wetland swidden (*lana*) sequence consists of grass clearance, the excavation of smaller internal boundary ditches and then two successive crops of taro and sweet potato, with vines dibbled directly into the garden surface. A second phase (*tabu*) sees fallow vegetation cleared and burnt, with the compost material generated forming the core of heaped soil mounds into which sweet potato vines are inserted. Following the first harvest from this *tabu* phase, the garden enters a third, mature phase as an established garden (*mabu*). Other crops traditionally cultivated in wetland gardens during the early part of this mature phase include sugarcane (*Saccharum officinarum*), yam (*Dioscorea alata*) and green vegetables such as *Rungia klossii*, *Oenanthe javanica*, *Rorippa schlechteri*, *Amaranthus* spp., *aibika* (*Abelmoschus manihot*) and cucumber (*Cucumis sativus*), all of them regarded by Huli as present in their repertoire well before direct contact with Europeans (Ballard 1995: 82–83). Post-contact additions include pumpkin, maize, choko (*Sechium edule*), various beans, pineapple, cassava, Chinese cabbage, onion and *Solanum* potato.

As wetland gardens age, the proportions of all crops other than sweet potato and sugarcane decline to the point where there is effectively a sweet potato monoculture. After a period ranging from about five years through to near-permanent reclamation, the length being contingent principally upon the needs of the garden's owners and their ability to maintain the surrounding drains, the garden reverts first to long fallow and, if not brought back into use, ultimately to swamp. The progression from swidden to burning of the cut grass for ashy compost, succeeded by mounding or bedding in an established garden, follows closely the sequence for a dryland garden, the two forms of garden thus sharing a common template.

The fertility and productivity of wetlands are probably sufficient to account for the attraction they hold for highlands communities. Table 5.4 gives figures for the yields of sweet potato from dryland and wetland gardens in the same locations. Although the estimates for yield in tonnes per hectare per year vary considerably amongst locations, the contrast between wetland and dryland productivity is relatively constant, suggesting that productivity from wetland gardens can be as much as twice that of dryland gardens. Based on Pospisil's (1963: Table 8) data, gardening in reclaimed swampland, which requires 217 hours of labour per tonne (hrs/t) of produce in the Paniai region, is also considerably more efficient than dryland agriculture (Pospisil's 'Extensive Shifting Cultivation'), at 360 hrs/t, but less efficient than wetland agriculture on swamp margins (Pospisil's 'Intensive Shifting Cultivation'), at 145 hrs/t (as calculated by Modjeska 1977: 153–155). But in terms of yield per square metre, wetland cultivation is the most productive of the

three forms, generating 1.69 kg/m², compared with 1.38 kg/m² from intensive dryland and 0.81 kg/m² from extensive dryland cultivations (Pospisil 1963: Table 24). Bayliss-Smith (1985a) also suggests that, despite labour inputs that are three to four times greater than those per unit area of forest swidden, wetland taro cultivation in the upper Kaugel produces yields that are two to three times greater. Figures for wetland taro yields vary widely, from 12 t/ha to as much as 30.6 t/ha for specific cultivars, with an average from crop trials near the Kuk Swamp site being 17.1 t/ha; generally, however, these figures compare favourably to taro yields from swidden gardens on slopes of 4.0–7.8 t/ha (Bayliss-Smith 1982: 137). Where the necessary labour inputs are available, wetland agriculture thus appears to be considerably more productive and efficient than its dryland counterparts, both for sweet potato and for its presumed precursor staple, taro (see Chapter 14, section ‘Labour and yields in Phase 4’).

Table 5.4 Sweet potato yields on dryland and wetland (tonnes per hectare per year).

Location	Dryland	Wetland
Paniai region	8.1–13.8	16.9
Grand Baliem Valley	10.0	20.0–25.0
Tari region	5.1–8.2	11.3–13.8
Upper Mendi	1.4–8.8	24.3

Source: See Table 5.2 for sources from which the data were taken.

A further significant difference between wetland and dryland systems has to do with the reduced crop repertoire cultivated in wetland gardens. The tendency to a virtual monoculture of sweet potato in established wetland gardens has major implications for the overall agricultural production of the gardening community. The balance sought in daily diets between sweet potato and leafy green vegetables (Pospisil 1963: 376ff; Powell with Harrison 1982: 93ff) is not reflected in this apparent imbalance in agricultural production, though the imbalance is partly offset in some highlands communities through the consumption of sweet potato leaves (particularly amongst Dani of the Grand Baliem Valley, Purwanto 1997: 215). Nor does population fluctuate proportionally with the large wetland areas brought into and out of use. During the 33 years between 1959 and 1992, the total area of wetland in use at Haeapugua in the Tari region fluctuated both up and down by as much as 43 per cent; yet over the same period the population resident in the area rose inexorably, almost doubling (Ballard 2001: 298). Why then is labour committed to wetland drainage, if the resulting wetland production is linked directly neither to population growth nor to the dietary needs of humans, and how is that labour marshalled?

Social contexts for wetland drainage

In most highlands societies, political autonomy is fiercely defended and individual men and their immediate families guard closely their right to garden independently of others. Wetland drainage can be undertaken successfully by individual families, but more commonly involves larger groups acting communally, at least in the construction of the garden. The advantages of working in a larger group include wider political and defensive support for what are often contested claims to areas of swampland that are vulnerable to attack, as well as the benefits of a more speedy completion of the initial tasks of drain excavation and garden construction.

Estimates of the labour required to create wetland fields are based on a variety of calculations at different locations and range from 7 m³/man-day in the Tari region (Ballard 1995: 187, over a 7.5 hour period) to 7.25 m³/man-day in the Paniai region (Pospisil 1963: 106, assuming 5 hours of labour per day) or 6 m in length of excavated drain per man per day in the Wahgi Valley (Gorecki 1985: 340–341, assuming 4.0–4.5 hours per day), though all three sets of figures

presume the use of modern steel spades. Experimental data from a range of sites relating to excavation with wooden spades (Bayliss-Smith and Golson 1992a: 15, 21) suggests a slower rate of 2.5 m³ or 1 m in length of drain per day (Bayliss-Smith and Golson 1999: 222), assuming an average volume of 2.5 m³ per metre of drain, removed at 0.5 m³ per hour for a maximum of 5 hours per day. As the total length of the visible drain network in the wetlands at Haeapugua (Figure 5.5) is calculated at just over 205 km, the rough 'wooden tool' rate of 1 m/man-day yields an estimated total of 205,000 man-days for the entire network; but does this represent the labour of 14 men working continuously, and improbably, over 40 years or, equally implausibly, of 561 men working every day for one year? Local oral traditions at Haeapugua suggest that most of the drain network was in fact created over little more than 40 years (Ballard 1995: 187), at an average of about 5 km/yr, while Gorecki (1985: 341; see Chapter 23 here) notes that drainage of the South Kuk wetlands was achieved over a period of 17 years, at an average of just over 3 km/yr. While such figures and estimates offer only a very general guide to labour investments, they do serve to stress the difficulty of deducing actual labour group sizes, or the time taken to establish a drainage network, simply from the scale of a field system, as well as the challenge of 'reading' social organisation from the form of a field system.

The ethnographic evidence for the social organisation of wetland production is invaluable here and it suggests that communal labour inputs, if not essential, are the common rule. Dani work parties in the Grand Baliem Valley of up to 15 men and boys are assembled by a garden owner and fed during the period of their labour, in the knowledge that they will call on his labour on their fields in turn (Heider 1970: 39); larger enterprises are initiated and coordinated by lineage heads (Schneider et al. 1993: 20–21; Purwanto 1997: 358). Huli work parties in the Tari region are coordinated in much the same way as for any other communal project—such as warfare or compensation payments—by one or more identified 'owners' (*andwane*) or 'sources' (*tene*) of the project. The capacity of project owners to marshal labour for wetland drainage, drawing on immediate family, affinal kin, friends and allies, is acknowledged as testament to their ability as leaders and contributes substantially to their prestige within the community. By the same measure, the longevity of a wetland garden project is a test of the capacity of a project leader to sustain the cohesion of his work party by ensuring that the drains are regularly maintained and the garden's viability repeatedly secured.

If the question of 'how' a wetland garden project is pursued is relatively simply observed and documented ethnographically, the corresponding question of 'why' wetland gardens are initiated is less easy to resolve. Disaggregating consumption of produce from wetland gardens from all other agricultural production is difficult, but interviews with wetland garden owners at Haeapugua suggest that wetland projects are usually directed towards some identifiable goal to which other project members might be recruited. Rather than simply alleviating shortfalls in dryland garden production, wetland projects are initiated with the goal of producing a surplus of sweet potato, a substantial proportion of which is reserved as fodder or forage for pigs. Estimates of the overall proportion of sweet potato production fed to pigs in several highlands societies range from 23 per cent to 70 per cent, but most commonly fall around the 50 per cent mark (Hide 2003: 63–70). The production of pigs, as the premium item of exchange in most highlands societies, whether for marriage or various forms of compensation, as well as for ritual sacrifice, requires a degree of long-term planning (Hide 1981: 561). Haeapugua Huli have described their wetland projects as initial steps in the process of preparing for major payments, or even in covert anticipation of conflict. To the extent that uncultivated wetlands are a common source of forage for pig herds, especially for earthworms (though introduced earthworm species appear to be more attractive for pigs than endemic species, Hide 2003: 71–72), wetland cultivation is thus in part a means of intensifying pig production within the same area.

Comparisons

This brief ethnographic overview of wetland field systems documented during the period since colonial contact suggests extensive similarity in techniques, crops and methods of production across much of the highlands region of New Guinea. There is evidence for considerable variability within individual systems (see, for example, Heider 1970: 42), sometimes greater than that between systems from different locations. However, the local continuities between dryland and wetland systems are sufficiently strong that these similarities should probably be interpreted as evidence for a broad agricultural heritage shared across the highlands, for continuities in environmental context and for the common hydrological requirements of drainage systems. However, this argument for an essential regional uniformity comes with an important proviso, articulated by Spriggs (1990: 184): individual wetland systems need first to be understood at the specific level, in terms of each of the factors discussed here, such as the characteristics of local hydrology and catchments and the local forms of demand on production and of labour organisation.

Denham (2005a) has argued that the rectilinear fields of archaeological Phases 3–6 at Kuk Swamp represent an invention indigenous to the highlands, which precedes and thus cannot be attributed to the influence of the arrival along the coasts of New Guinea of Austronesian-speaking communities. While the claim that wetland drainage has developed independently in the New Guinea highlands now appears secure, the argument about the rectilinear form of the wetland field systems is probably not required, as rectilinear drains are a measure that is largely dictated by hydrological requirements and by the nature of land subdivision in a novel environment. There is certainly no support for an exogenous origin for highlands wetland drainage evident in the tool repertoires or the various highlands vocabularies for wetland agriculture, all of which are embedded firmly in the wider technologies and lexicons of local dryland agriculture (Ballard 2000). For the later Phases 5 and 6 at Kuk, the ethnographic analogues of the 20th century discussed here offer real interpretative possibilities, identifying anthropogenic wetlands along the dryland/swampland margins as the agricultural powerhouses of production and innovation and confirming the role of pig production and the intensification of social exchange as critical stimuli for communities confronted with the social and technological challenges of swampland reclamation.

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