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Stress on tropical karst cultivated with wet rice: Bohol, Phillippines

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Abstract Wet rice cultivation represents one of the most intensive uses of tropical karst. Under wet field conditions karstlands can be highly resilient, but nevertheless vulnerable to change. The karst environment in this study has been cultivated for at least five centuries. However, the post-World War II era has fostered a host of pressures that have altered the local ecology. Resulting stress in the irrigation systems and society threaten the maintenance of this viable karst-based agricultural economy.

Key words Tropical Karst—Rice cultivation—Agroecosystems

Introduction: Karst, wet rice and sustainability

Wet rice cultivation represents one of the most intensive, yet potentially sustainable, uses of karst terrain. High and sustained yield, however, are achieved only with appropriate technologies and astute management. Karst-based wet rice agroecosystems of great antiquity that continue today are known in just a few sites in Southeast Asia: Bohol, in the Philippines (Urich 1989), the Toradja uplands in Sulawesi (Nooy-Palm 1976), and a number of sites in southern China and northern Viet Nam (Cuc and others 1990; Zhao 1986). There have been few studies of these living karst agroecosystems that addressed their antiquity and the technological and social devices used to sustain longevity (Nibbering 1991; Urich 1989). Such studies are valuable in today's rapidly changing world, in which new and powerful pressures threaten the sustainability of long-viable systems.

This paper reviews the historical development, resources, and human manipulation of one tropical karst environment, citing examples from three of the six irrigation systems existing in the municipality of Batuan on the Philippine island of Bohol (Fig. 1). Bohol's 500-year history of sustained karstland occupation is seriously threatened today by the pressures of population, inappropriate application of agricultural technologies, and civil strife. This review is intended to expand knowledge of karst resource management, and highlight the problems that modernization has wrought; it also seeks to dispel perceptions of tropical karst as an unsustainable environment.

Bohol: "A rocky and barren island of Rice"[1]

Wet rice requires large quantities of flowing water at the land surface. This has fostered the perception that such a land use is unsuitable for karst landscapes (Spencer 1959; Wernstedt and Spencer 1967). In some instances karst is described as porous, drought prone, and analogous to "desert margins" in fragility and capacity (Daoxian 1988). Others portray karstlands as inhospitable and expect them to be, "the last terrain to be intensively settled and cultivated" (Gillieson 1988; p. 98). However, Bohol has developed a highly sophisticated wet rice economy drawing heavily upon a wide range of karst resources (Uhlig 1986; Urich 1989).

The municipality of Batuan in the karst upland of Bohol (Fig. 1) displays a specialized wet rice agricultural system that developed over centuries in relative isolation from external colonizing, and often ecologically degrading, forces. However, since World War II a variety of external and internal forces have altered traditional community resource allocation and management practices. These changes have had widespread impacts. Most notable is a

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[1] Quotation from the commander of the British forces which seized the island from Spain in 1762

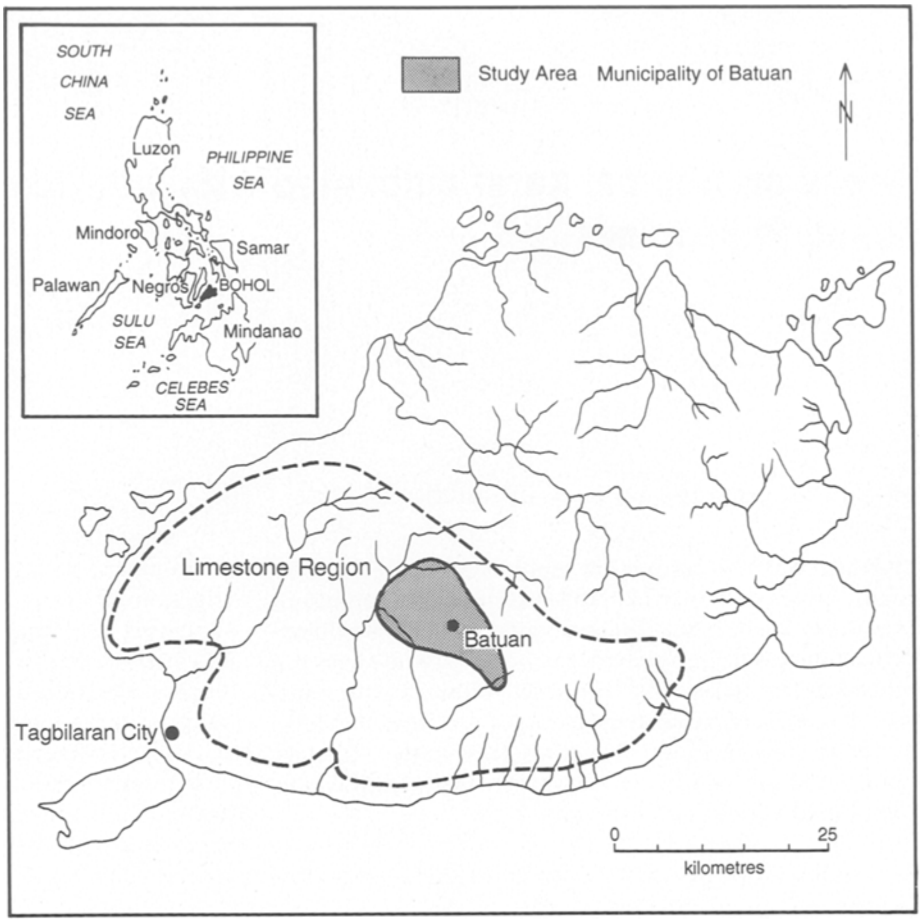

Fig. 1. The location of the Batuan municipality, Bohol Is., Philippines

Fig. 2. A karst corrosion plain (open polje) adapted to paddy field cultivation, Batuan

changing hydrology in response to specific changes in cultural ecology.

Landforms typical of tropical karst are found throughout the limestone region of Bohol. They are formed predominantly in the Maribojoc Formation, a marly, poorly consolidated limestone that rests on interbedded limestones and shales of the Carmen Formation. Landforms include cone-shaped, isolated residual hills (mogotes, also known as haycocks), more elongated interfluve residuals, and some massive metamorphosed limestone blocks that may reflect the influence of localized magmatic upwelling. Karst depressions, although occasionally subcircular and closed, are usually elongated in series along discontinuous valleys. In some areas they are narrow and elevated, opening to wide, polje-like flats (Fig. 2). There are many caves, small sinkholes (or swallets), springs, and tufa dams.

Slopes are highly variable, with two thirds of the municipality sloping below 8 percent. The lands steeper than 8 percent are almost entirely on limestone residuals hills. Just over 56 percent of Batuan's nearly 8000-ha area has slopes less than 3 percent. Nearly half of this 56 percent has a saturated bedrock surface and/or access to gravity-fed spring water irrigation and is cultivated with wet rice (*Oryza sativa*). The remaining relatively flat land lacks access to irrigation and is planted to white corn (*Zea mays*), coconuts, taro, ubi (*Dioscorea alata*), sweet potato, peanuts, bananas, tomatoes, mangoes, jackfruit (*Artocarpus heterophyllus*), star apple, coffee, or cacao. A small percentage of the comparatively flat land is in pasture, developed for settlement or, in isolated instances, remains forested.

A part of the 12 percent of Batuan that has slopes between 3 and 8 percent is adjacent to spring water irrigation sources and is often terraced and cultivated with wet rice. If there is no water source, these lands are dry-farmed, with white corn prevailing. The majority of slopes greater than 8 percent are found on individual mogotes. Few of these have been terraced; instead, they are cultivated with coffee and cacao, plus root crops and fruit trees on the steeper slopes. Increasingly, the flatter mogote summits are used as pastures, replacing the natural forest there. The image created is thus of various crops encircling each residual hill, although this is not invariable; each mogote has its distinct land-use history.

Batuan's economy is dependent on agriculture, with the production of a wide variety of crops. However, rice and corn account for 85 percent of the production with wet rice, cultivated on 39 percent of the area, providing 55 percent of the municipality's cash income. Maintenance of the wet rice environment thus is critical to both the subsistence food base and the monetary economy.

Precipitation and irrigation

Water, its location in the karst, and the seasonality of precipitation to a large degree dictate the type of technology required to develop a particular cultivation regime. In Batuan annual precipitation averages between 2000 and 3000 mm with the majority falling between May and January. A short but irregular dry season extends from February through May, although longer dry periods and serious droughts are not uncommon. This variability has fostered the development of irrigation systems with multiple functions. In the dry season the systems are protective, providing the water necessary for crop production. In the wet season they supplement the rains and also remove the excess water often associated with typhoons. In this intensively cultivated karst environment removal of excess water can be as important as its provision.

Karst resources used in wet rice cultivation

Storage

Water in the Bohol karst is stored in mogotes, in partially flooded caverns, and in lower, saturated bedrock including some epikarst. Mogotes are most important. They are composed of marly, poorly consolidated limestones which, when undisturbed, can absorb and transport large quantities of autogenic groundwater. The water debouches as springs where the mogotes contact valley floors.

There is surface access to at least three flooded caverns in Batuan. At base flow their average capacity is nearly half a million liters. The volumes of groundwater held in saturated bedrock beneath the paddy fields are difficult to estimate. They vary over short distances, from season to season, and according to their relationship with irrigation canals.

Conveyance and control

Canal and water diversion technologies tend to be more diverse and complex than the water and soil retention practices. The distribution networks consist of canals of varying size, generally constructed with local materials. The building material controls the design and efficiency of the canals to a large degree.

The canals are sited on the most impervious rock. Water losses via percolation vary with bedrock characteristics, depth to the saturated zone, and the gradient of the canal. When water is diverted away from a canal during a dry spell, the depth to saturated bedrock rapidly drops. System leakage thus is more profound during the early phases of a seasonal irrigation program and diminishes with time.

Stone construction is common. Stone-built canals may be either free standing or linings in a trench excavated in the soil. Individual stones vary widely in size but seldom exceed 1 m in diameter. The stone was derived from the paddy lands and surrounding hills, plus some small-scale quarrying (Urich 1989). Most of the stone masonry predates oral history but small parts some of free-standing canals have been constructed during this century.

Caves and canals excavated in bedrock are used sparingly in the conveyance of water but have played an important role in extending irrigation locally. They are also used to drain excess water. A cave passage 340 m in length in Bonogan is used to convey irrigation water from an upper section to a lower section of the system communal irrigation (Fig. 3). Other systems have sections linked in a similar manner but using shorter caves (less than 20 m). In total more than 400 m of cave passage are used to convey water between sections of the three irrigation systems studied. The length of caves used to remove excess water must be considerably greater.

When it is saturated, the comparatively soft Maribojoc limestone can be excavated easily with a sharp stick or a harder stone or metal tool. The aggregate length of excavated canals noted in the three irrigation systems exceeds 500 m. Most sections are short and seldom more than 20 cm deep. An exceptionally long (170 m), deep (1 m), and wide 0.75 m) excavation is found at the lower end of the Bonogan system immediately below what was probably a natural sinkhole that terminated surface flow. This excavation permitted the irrigation of an additional 10 ha of land. Where it was notched to allow the water to flow off the

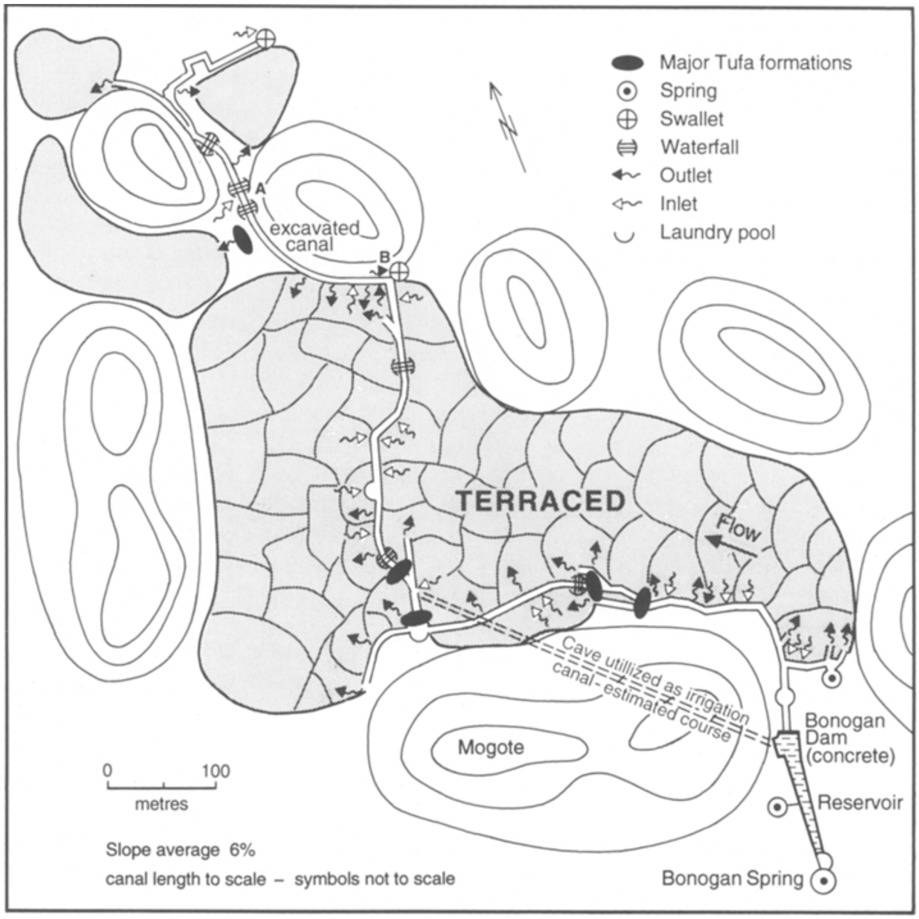

Fig. 3. Map depicting the communal irrigation system of Bonogan Spring

side of a mogote into the paddy, there is a tufa deposit that covers an area of nearly 50 square meters to a depth of 1–2 m. A formation of this size and extent requires a substantial period to accumulate.

Diversion structures

Gravitational irrigation systems rely on natural or artificial head falls to distribute water. Farmers divert water to paddies at points of natural fall over tufa dams, etc., by using stone or logs. Diversion structures at other places may be temporary, using small rocks, mud, sticks, banana and taro leaves, and coconut husks. Some major diversion points are built and disassembled on a weekly basis. More permanent structures are built on larger canals with large limestone cobbles, sticks, logs and, infrequently, finished lumber. Permanent stone diversions are 1–2 m thick and up to 1.5 m high, rendering them resistant to washout. Logs are more susceptible but have the advantage of ready availability and easy replacement.

Terracing

A majority of springs used for irrigation in Batuan discharge at the valley floor, the same level as the paddy. Where a major spring is located higher, the land below it is terraced down to floor level. Only 20 percent of riceland in the study area is terraced, but it is of great importance to general system viability. Terraces built immediately downstream of the water source dissipate flood waters, reduce soil erosion, and increase water retention. On the social level, terraces provide permanent property delineation important to the stability of land management. They are constructed of soil, stone and, in isolated instances, coconut logs. Stones are strategically placed where water spills from terrace to terrace in order to absorb its erosive energy.

Drainage

The three irrigation systems all terminate at swallets or larger sinkholes, which are termed *hophopan* in the Boholano language. All systems are designed with the capacity to transport water directly from spring to sink without passing through any paddy fields. This is extremely important during floods. Fortunately, the downstream caves that drain the systems have capacities equal to those of the canals feeding to them.

Upstream, where there is a cave adjacent to a canal, it will be used for temporary floodwater diversion. More numerous and of equal importance are tiny swallets within the paddies themselves. They are typically about 10 cm across. Farmers usually plug them, especially during periods of diminished water supply. However, when high water threatens a young rice crop or when wet weather may delay ripening of the crop, the sticks and leaves plugging the swallet are removed to allow the water to drain freely.

The slopes of the larger sinkholes (5–10 m across) are occasionally planted with taro, gabi, or bananas, emulating what Spencer and Hale (1961) termed "taro pits." Sinkhole sides and floors are closer to the water table, thus providing excellent growing conditions. Batuan's natural taro pits provide sustenance during drought and reduce soil erosion because they remain heavily vegetated.

The forces of change

The municipality of Batuan developed a highly specialized wet rice agricultural system indigenously over centuries or longer, in relative isolation from external colonizing and often ecologically degrading forces (Urich 1989). However, since World War II, many different external and internal forces have combined to alter traditional community resource allocation and management practices. These changes have had widespread impacts.

There were three principal causes of change—increasing population, the adoption of green revolution technologies, and an on-going peasant insurgency and government counter-insurgency. Changes include disruption of land-use strategies, disorganization of peasant labor organizations, and intensified destruction of landforms. Most affected is groundwater quantity and quality, both of which are vital to the maintenance of the sustainable agricultural economy.

Population

In Batuan the rate of population growth has outpaced government expectations. The 1970 population stood at 8712, for a density of less than one person per hectare. The 1989 population projection was 10,000, but this was exceeded by almost 2000 (A. Virador, unpublished data, 1989). In 1980 (the most recent published data), the municipal birth rate was 3.3 percent (Republic of the Philippines 1980), although the overall population growth rate is estimated to be lower at 1.85 percent due to continued outmigration, primarily of young men.

Batuan's population of 11,729 in 1989 (1.48 persons per hectare), consisted of 1948 farm families and 480 nonfarm families who are considered landless. The largest components were married females and unmarried females over the age of 21, together accounting for 41.2 percent of the population. Males over 21 constituted 28.2 percent and youth of both sexes between the ages of 10 and 20 constitute 20.8 percent. The smallest percentage, 9.8, was comprised of those under the age of 10 (A. Virador, unpublished data, 1989). The imbalance in the adult sex ratio is due to the migration of young men. The startling reduction in the percentage of the population under the age of 10 is the result of population growth control programs initiated in the 1980s which, through tax incentives, hope to limit families to an average of four children.

Agriculture

Like most tropical, less-developed, rice-growing regions, Batuan remained relatively pristine in an agricultural sense up to the end of World War II. Widespread penetration by outside development forces began with the introduction of the green-revolution-based Masagana 99 program in January 1973. This was presented as a package to small farmers that included low-interest loans with no requirement of collateral, high-yielding varieties, fertilizers, pesticides, and herbicides. Initial acceptance of the program was strong, but the tide turned after environmental problems were noted, including a rapid decline in the number of bird and aquatic species, and water buffalo deaths linked to pesticide contamination.

Currently, high-yielding varieties are widely used for the wet season crop (June–December) while indigenous varieties, which perform better and retain cultural significance, are used for the drier season crop. Pesticide use has declined as a result of the severe environmental problems. Fertilizer use has been largely maintained by yearly subsidy programs, part of province-wide rice production initiatives.

Insurgency and counterinsurgency

Since the late 1970s Batuan's population has experienced extremely high stress because of armed Maoist insurgents operating in the municipality's hinterlands, and the government counterinsurgency program that they attracted. Military policies have focused on population relocation and infrastructure development. Historical settlement patterns were disrupted by the rapid, widespread movement of families and kinship groups out of their traditional, dispersed ancestral house sites to strategic hamlets. As a result, virtually every family in the peripheral areas of the municipality has been recently relocated adjacent to lowland paddy, close to village cores, or along a road. In most cases the distance between traditional and relocation sites did not exceed a few kilometres but, nevertheless, the resulting social disruption is marked.

Impacts on social and environmental resources

Increasing population density, new agricultural technologies, and insurgency and counterinsurgency issues have introduced imbalances into the long-evolved cultural ecology of Bohol's limestone region. Nevertheless, the karst dwellers and development agents feel compelled to alter the cultural use of the karst environment even further in hopes of "developing" it. This means the continued introduction of new technologies, over exploitation of specific natural features, and alteration of social structures. End results include quantitative and qualitative changes in groundwater, but water resource degradation is just part of a complex process of physical and cultural degeneration as declining irrigation water supplies apply pressure to allocation procedures, which stresses the conflict resolution mechanisms, with further stress upon resources.

Social institutions

Communication and support networks and garden and small livestock enterprises have been altered by the removal of cultivators from their traditional house sites. For instance, a number of informal self-help organizations that aid families during periods of financial or psychological stress such as *gala* (marriage) and *dayong* (death) have been disrupted by the splitting of kinship groups and the distrust of such institutions by government forces. The *hongos*, a communal laboring organization, is most closely associated with development of agricultural land; a hongos may repair an irrigation system, construct terraces or plant trees. These are all activities that because of time, skill, and energy require a pool of labor. They have been disrupted in ways similar to that of the social organizations noted above, but their decline has been exacerbated by the formalization of private property rights and a change toward a cash economy.

In response, the local population has come to require increasing inputs of money and technology from government and development agencies. Increasing reliance on such agencies is flawed by their lack of understanding of karst processes and potential. Disruption of the local hongos has been particularly important because they understood environmental limitations and developed creative solutions, such as the construction of terraces for erosion control and cave and or swallet management for regulation of irrigation water.

Groundwater quantity

My informal interviews indicate that all parties (farmers, politicians, business persons, journalists) foresee a hydrological calamity in Bohol's karst upland (Bohol Chronicle 1990). It is believed that spring discharges may have declined by 40 percent over the last 20 years (Apolonio Virador, personal communication, 1989). Climatic records do not correlate with this steep decline; shifts in land use and resource allocation are its more likely causes.

Some controversy surrounds the role of deforestation in reducing karst spring flow and lowering groundwater tables. However, there is a solid case for it in Batuan (Hamilton and King 1983, p. 125) where deforestation and conversion of lands to other intensive uses has increased in area and frequency with the expanding population but finite wet rice lowland base. When interviewed, many of Batuan's farmers reported that small rock-carved cisterns in the flanks of forested mogotes completely dried upon forest clearance. Apparently when well forested, meteoric water is retained and enters the hydrological cycle of the marly, poorly consolidated, Maribojoc Formation. When deforested, row cropped, or converted to pasture, water runs off rapidly on the surface, resulting in reduced groundwater recharge and severe erosion.

A second cause of reduced agricultural spring flow is the development of piped domestic water systems. The first were constructed in the late 1960s, and new systems are being developed as the population becomes more agglomerated. Spring water vital to irrigation is diverted to domestic use; it suffers from severe system leakage en route and wastage in the home on arrival.

A third and more insidious form of resource degradation involves the quarrying of mogotes for road stone. This activity has a long history beginning with a highway construction program in the 1920s. The soft, marly limestone is accessible, easily quarried, and an excellent, cheap road-building material.

The effect of the shift in resource exploitation from agricultural to nonagricultural activities is a destabilized groundwater reserve. For example, there is an abandoned concrete aqueduct at the terminus of one irrigation system

Fig. 4. Recent and widespread deforestation and cropping of hills has occurred in Bohol karst

because irrigation is no longer feasible there. Dry season rice crops are stressed increasingly by inadequate irrigation water supplies. Batuan has not experienced a widespread and devastating drought since 1983 [but see Postscript—Ed.]. Since that year deforestation of the uplands has continued unabated, resulting in less than adequate irrigation water supplies in 1985 and 1988 when precipitation was only slightly deficient. In the past, such minor fluctuations in precipitation would be compensated by adequate supplies of groundwater.

Groundwater quality

Indiscriminate application of pesticides decimated the local egret population during the 1970s and 1980s, reducing it from ~10,000 to an estimated 18!

Traditionally farmers fished in the irrigation canals using leaves of the tigao shrub (*Callicarpa paloensis*) as a natural stunning agent. With the coming of pesticides, farmers poured them directly into the canals to stun fish. Water buffalo wallow in and drink canal water from the canals, and so came to suffer severe, often fatal, dysentery. Use and abuse of chemicals is also linked to extinction of fish and crustaceans in cave systems. There were no reports of human illness related to herbicide and pesticide abuse but, given the nature of the karst system and the inability to diagnose environmentally related sickness accurately, cases may have occurred.

Today, industrial pesticide and herbicide use has been curbed at the initiative of the local Department of Agriculture, which controls the municipality's only sprayer. While spraying is now discouraged, agricultural agencies continue to introduce new chemicals into the market place.

The other important nonorganic pollutants are laundry soap and bleach. The impact of commercial detergents is most apparent at the end of the hot, dry fallow of April and May. As irrigation begins, the combination of heat, water, and phosphates leads to extensive algal blooms, some of which completely envelop paddies. Algae are not inherently degrading; however, competition with other high-quality nitrogen-fixing aquatic plants such as azolla (pinneta fern) and their toxicity to mammals may have severe impacts.

Disposing of human and animal wastes in Batuan has also caused numerous problems. Crude population density is about 1.48 persons per hectare. However, when the feces of the municipality's 2556 pigs are added, the equivalent density rises to 2.43 persons per hectare.

Needless to say, potability tests indicate that the water is severely contaminated by human and agricultural wastes. Local waterborne diseases include gastroenteritis, typhus, and internal parasites. Statistics for the 1980s show a steady case load of diarrhea with little monthly fluctuation except in July and August, when there is some increase associated with large feasts at fiesta time. 1983 was a drought year when contaminants became more concentrated and the case load more than doubled in many months.

Conclusion

The indigenous irrigation systems of Batuan appear on the surface still to be operating smoothly and efficiently. Deeper examination, however, reveals that the physical and chemical sustainability of the irrigated lands is being undermined. Specific reasons for degradation include one, or a combination, of the following: introduction of inappropriate agricultural technologies, decline of group labor organizations (hongos) as a result of forced resettlement of noncombatants, changes in upland land use, quarrying of mogotes, and shifts in water resource allocation from agricultural to domestic consumption. Of greatest consequence both now and in the future is the continued deforestation of the uplands, which has already had widespread impacts on the regional hydrology. It appears that these pressures of both external and internal origins have stressed the physical resource base possibly further than it has been pushed before.

Authors's postscript from the field

In the first four months of 1992 Batuan received only 85 mm of rainfall, or 18 percent of the average for those months during the previous 23 years. The drought is associated with the El Nino disturbance. Environmental and social impacts have been the most severe that residents can recall.

Countless springs resistant to typical dry season stress have dried up this time. At an alarming rate, fields once planted exclusively to wet rice are being converted to corn, a much less productive and culturally acceptable product. Piped domestic water supplies are greatly reduced. In one area a spring yielding an average of 1.8 m^3/day is serving 1000 persons. A diarrhea outbreak has occurred there, with some persons requiring hospitalization.

The climatic severity of this drought is not as acute as that of the El Nino drought of 1983 (46 mm over five months). Changes of the last decade including population increase, intensification in upland cultivation, deforestation, and continued quarrying, plus a lack of appropriate planning, are the root causes of this exceptional hardship.

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