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Andrew Sluyter

Louisiana State University, asluyter@lsu.edu

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Intensive Wetland Agriculture in Mesoamerica: Space, Time, and Form

Andrew Sluyter

Department of Geography, The University of Texas at Austin

Over the past four decades, geographers have led the effort to better understand Prehispanic, intensive wetland agriculture in Mesoamerica (Siemens 1992; Siemens and Puleston 1972; Turner and Harrison 1983; West and Armillas 1950; Wilken 1969). Their research and that of scholars in allied disciplines has increased our knowledge of past landscapes and human ecologies (Sluyter and Siemens 1992), of the relationships between agricultural and social processes (Scarborough 1983a), and of the viability of alternatives to industrial agriculture (Chapin 1988; Gómez-Pompa 1978). In the time since Denevan (1980a; 1982) and Turner (1983a) last reviewed this literature, however, a great deal of new information has accumulated, and it invites a spatial-temporal analysis that addresses the central themes that have emerged and that serves as a point of departure for further investigation.¹

This paper focuses on four broad themes reflective of the diversity of scholars involved in the investigation of Mesoamerican landscapes and human paleoecologies. The first of these themes assesses the role of intensive wetland agriculture in the emergence of sedentism, urbanism, statism, and anthropic environmental change. The second explores the interrelationship between intensive wetland agriculture and other agroecosystems, both intensive (terracing and canal irrigation) and extensive (wetland and dryland shifting cultivation). The third focuses on wetland agriculture's ecological parameters, i.e., morphometries, functions, crops, construction techniques, and environments. And the fourth addresses attempts to reconcile the touted productivity and sustainability of intensive wetland agriculture with its now largely vestigial expression. These themes, reflective of the

complex processes of ancient Mesoamerica's ecology, quite necessarily are interrelated.

Terms and Methods

"Mesoamerica" has its time and space (Kirchhoff 1943; Porter Weaver 1981). In time, Mesoamerica refers to the period before Spaniards and Native Americans intersected ca. A.D. 1520. During this Prehispanic period, Mesoamerica became one of two regions of the New World that contained urbanized states—the other being Andean America. In space, Mesoamerica encompassed what is today southern Mexico, Guatemala, Belize, El Salvador, and parts of Honduras, Nicaragua, and Costa Rica (Figure 1). Nonurban peoples bounded the region on the north and south. In a succession of Prehispanic periods, the Olmec, Zapotec, Teotihuacán, Maya, Toltec, and Aztec peoples dominated various subregions of Mesoamerica. These peoples built cities, wrote books, and practiced astronomy, but above all they were farmers—distinguished by their development of intensive wetland agriculture, canal irrigation, and terracing.

"Intensive wetland agriculture" goes by various names: raised fields, ridged fields, ditched fields, *camellones*, platform fields, *chinampas*, island fields, island beds, drained fields, ditched/drain fields, channelized fields, and mounded fields (Denevan 1980b; Denevan and Turner 1974; Jacob 1992; Mathewson 1985; Vasey 1983). Whatever the name, this form of agriculture occurs in various contexts: along streams, in lake basins, and at springs. It likewise reflects various construction techniques: ditching into the natural surface, mounding above the natural surface, or both. But in all cases, and despite varying circum-

Figure 1. Locations of known intensive wetland agriculture. Sources: Table 1; Base map: Porter Weaver 1981: Map 1.

stances, its purpose seems to have been the same—to regulate soil moisture in the root zone and to maintain a nutrient sump in the canals which farmers periodically might apply to their field surfaces. Also in all cases, this agricultural system was contingent upon water tables at the soil surface for at least part of the year. In seasonally dry environments, farmers accelerated drainage as the water table fell at the end of the wet season, and then retained water in the canals for splash and subirrigation during the ensuing dry season, possibly also planting crops in the bottoms of the drier canals. Other farmers lowered a perennially high water table or raised planting surfaces above the water surface. In all cases, farmers took advantage of wetlands by adjusting the relative elevations of the root zone and the water table to maintain the degree of soil moisture most advantageous for crop growth; they accord-

ingly intensified production by investing in an infrastructure that increased yields and decreased risks. This commonality suggests “intensive wetland agriculture” as a generic term which subsumes a wide variety of field types, modes of construction, and functions peculiar to specific contexts.

Morphometrically, intensive wetland fields vary widely (Figures 2, 3, 4). Three morphological aspects are pertinent: 1) profile, or the cross section along the short axis of fields and intervening canals; 2) shape, or the plan of individual fields within a complex; and 3) pattern, or the overall plan of a field-canal complex (Denevan 1970; Mathewson 1985). Metrical variation adds further complexity. While canal width, field width, and field length are basic, amplitude, i.e., the vertical distance between field surface and canal bottom, and frequency, i.e., the number of field-canal pairs

Figure 2. A vestige of Prehispanic intensive wetland agriculture at Río San Juan in the Gulf Coast subregion. For location, see Figure 1.

over a given horizontal distance, are related variables.

Extensive agriculture also occurs in Mesoamerican wetlands today, and doubtless it did so in Prehispanic times. The *marceño* of Tabasco, Mexico, a flood-recessional cultivation technique, offers a case in point (Orozco-Segovia and Gliessman 1979). But extensive agriculture of this sort is ephemeral, requires little investment in field infrastructure, and effects little in the way of enduring landscape modifications. Researchers have relied on ethnographic and historic analogs and on ecological models. Moreover, extensive agricultural systems that depended on the natural soil moisture regime entailed high risk of crop failure and low yield that made them unlikely candidates to support dense populations.

For these reasons of evidence and interpretation, this paper focuses on intensive wetland agriculture—hereafter termed “wetland agricul-

ture” or “wetland fields.” A review of the literature (Table 1)² provides the basis for a spatial-temporal analysis that employs a chronological diagram (Figure 5) and a series of maps (see following figures) to identify relationships among three variables: 1) distribution; 2) hectareage; and 3) morphometry. Five distinctive subregions defined by physiography (West 1964) and culture (Porter Weaver 1981) frame the spatial analysis (Figure 1 and Table 1): 1) the Mesa Central; 2) the Southern Highlands; 3) the Gulf Coast; 4) the Maya Lowlands; and 5) the Maya Highlands. Three periods frame the temporal analysis (Figure 5): 1) Preclassic (2500 B.C. to A.D. 1); 2) Classic (A.D. 1 to 900); and 3) Postclassic (A.D. 900 to 1521). These periods signal ecological transformations: as a sketch, the widespread emergence of agricultural sedentism during the Preclassic, urbanism during the Classic, and large states during the Postclassic (Porter Weaver 1981). The database

Figure 3. Extant intensive wetland agriculture at Xochimilco in the Mesa Central subregion. For location, see Figure 1.

relies on the primary researchers' conclusions, even when drawn on scant data and relative rather than absolute dating methods. In some cases, measurements of diagrams, maps, and photographs rather than explicit statements yield the hectareage and morphometric data.

Regional Patterns

The Mesa Central

The Mesa Central is the southern portion of the Mexican Altiplano, a high-altitude plateau interrupted by volcanic ranges and basins. The generally subhumid and temperate climate has a wet-summer, dry-winter precipitation regime. Owing to the winter dry season and to frosts, rainfed agriculture is only possible during the summer. Intensive wetland fields occupy a series of volcanic basins that stretch in an arc from northwest to southeast (Figure 1).

Early researchers focused their attention on *chinampas*, the prominent wetland fields in the Xochimilco-Chalco subbasin (Humboldt 1966; Nuttall 1925; Santamaría 1912; Schilling 1938). Since the 1940s, when investigators began to apply techniques to estimate chronologies and hectareages (Armillas 1971; Avila López 1991; Serra Puche 1988; West and Armillas 1950), research has accented the role of *chinampas* as the subsistence base for the Aztec and, perhaps, Teotihuacán states. In addition, a series of related studies has examined extant *chinampas*, often emphasizing their productivity and sustainability as a model for current development efforts (Moriarty 1968; Gómez-Pompa 1978; García Mora 1979; Rojas Rabiela 1983a; 1991; Wilken 1985; Niederberger 1987; López Ríos 1988).

Other basins in the Mesa Central have elicited less attention. Wilken (1969) has studied extant fields in the Puebla-Tlaxcala Basin, but their changing spatial and temporal distribu-

Figure 4. Morphometry of intensive wetland agriculture.

tions remain little known (García Cook 1985) save for the fields at Amaluca (Fowler 1987). Both extant and vestigial fields in the Huamantla and Toluca basins have received but little attention (Sugiura Yamamoto and Serra Puche 1983). And while Weigand (1993) has directed attention to large hectareages of fields in the Etzatlán and Teuchitlán basins near Guadalajara, research there remains at an early stage.

The Southern Highlands

The Southern Highlands, a series of highly dissected mountain ranges located between the Balsas Depression and the Isthmus of Tehuantepec, yields meager evidence of intensively cultivated wetlands. The generally

temperate climate has a wet-summer, dry-winter precipitation regime. The only known instance of intensive wetland fields occurs at San Antonio Arrazola in the Valley of Oaxaca (Wilken 1969), one of the few large expanses of alluvium in the Southern Highlands (Figure 1). While these extant fields remain unstudied, their proximity to Monte Albán—the dominant Classic-period settlement in this subregion (Porter Weaver 1981)—hints at the possibility of Prehispanic origins.

The Gulf Coast

The evidence of intensive wetland agriculture is more plentiful in the Gulf Coast, a plain that fronts on the Gulf of Mexico. The generally

Table 1. Post-1940 Sources Pertaining to Intensive Wetland Agriculture in Mesoamerica.

Location Number ^a	Location	Sources
		Mesa Central
1	Etzatlán Basin	Weigand 1974; 1991; 1993
2	Teuchitlán Basin	Weigand 1974; 1991; 1993
3	Toluca Basin	West and Armillas 1950; Sugiura Yamamoto and Serra Puche 1983; personal observation, 1992
4–10	Basin of Mexico	Palerm 1955; 1973; Rojas Rabiela et al. 1974
4	Teotihuacán	Sanders et al. 1970; 1975; Millon 1973; Sanders 1976a; Sanders et al. 1979
5	Zumpango	Palerm 1973
6	Xaltocan	West and Armillas 1950; Palerm 1973; Brumfiel and Frederick 1992; Nichols and Frederick 1993
7	Eastern Texcoco	Apenes 1943; Noguera 1943
8	Tenochtitlán	Calnek 1972; 1973; 1976; 1978; Palerm 1973
9	Iztapalapa	Palerm 1973; Avila López 1991
10	Xochimilco-Chalco	Coe 1964; Armillas 1971; 1987; Palerm 1973; Tolstoy 1975; Parsons 1976; 1991; Tolstoy et al. 1977; Smith and Tolstoy 1981; Parsons et al. 1982; 1985; McClung de Tapia et al. 1986; Serra Puche 1988; 1990
11–12	Puebla-Tlaxcala Basin	Wilken 1969
11	Puebla-Tlaxcala	Wilken 1969; 1970; 1987; García Cook 1974; 1981; 1985; 1986; Abascal and García Cook 1975; Prem 1975; Abascal et al. 1976; García Cook and Merino Carrión 1990
12	Amalucan	Fowler 1969; 1978; 1987; Woods and Fowler 1989
13	Huamantla Basin	personal observation, 1992
		<u>Southern Highlands</u>
14	San Antonio Arrazola	Wilken 1969
		<u>Gulf Coast</u>
15	Estero de la Llave	Siemens 1982a; 1983a; 1989
16	Estero Tancochín	Siemens 1982a; 1983a; 1989
17	Río Metropolitano-Estero Milpillas	Siemens 1982a; 1983a; 1989; Wilkerson 1983
18	Estero de Oro Verde	Siemens 1982a; 1983a; 1989
19	Río Tuxpan	Wilkerson 1983
20	Río Cazonés	Wilkerson 1983
21	Río Tecolutla	Wilkerson 1980; 1983; Siemens 1982a; 1983b; 1989
22	Estero de Tres Bocas	Schmidt 1977; Siemens 1982a; 1983b; 1985; 1989; Wilkerson 1983
23	Río Nautla	Siemens 1982a; 1983a; 1989; Wilkerson 1983
24	Río Colipa	Siemens 1982a; 1983a; 1989; Wilkerson 1983

humid and hot climate, with a wet-summer, dry-winter precipitation regime, limits rainfed agriculture, particularly in central Veracruz (Figure 1, locations 25–28) where the dry season is most intense. Vestigial fields occur in backswamps near the mouths of streams that head in the highlands to the west. Schmidt (1977) first noted fields at Estero de Tres Bocas, and Wilkerson (1983), Stark (1990a), and Siemens (1980; 1992) have followed with further investigations. Nonetheless, these fields remain

largely unstudied, save for those at Estero de Tres Bocas, Río Tecolutla, and Río San Juan.

The Maya Lowlands

The climate of this low-elevation limestone peninsula—punctuated by karst landforms such as *bajos* (poljes) and *cenotes* (collapsed dolines)—generally is hot and humid, the winter dry season longest in the north and absent in

Table 1. continued.

Location Number ^a	Location	Sources
		<u>Gulf Coast</u>
25	Arroyo Naranjillo	Siemens 1979; 1980; 1983b; 1983c; 1989; Sluyter and Siemens 1992
26	Río San Juan	Siemens 1979; 1980; 1983b; 1983c; 1989; 1992; Siemens et al. 1988; Hebda et al. 1991
27	Río Jamapa	Siemens 1979; 1980; 1983b; 1983c; 1989
28	Laguna Mandinga	Siemens 1979; 1980; 1983b; 1983c; 1989
29	La Mixtequilla	Stark 1977; 1990a; 1990b
		<u>Maya Lowlands</u>
		Adams 1980; 1982; 1983; 1991; 1993; Adams et al. 1981; 1990; Pope and Dahlin 1989; 1993; Dunning et al. 1991; Dunning n.d.
30	Edzná	Matheny 1976; 1978; 1982; Mathney and Gurr 1983; Mathney et al. 1983
31	Río Candelaria	Siemens and Puleston 1972; Siemens 1989
32	Río Usumacinta group	Siemens and Puleston 1972; Siemens 1989
33	Río Azul	Adams 1984; 1990; Black and Suhler 1986; Black 1987; Culbert et al. 1990
34	Bajo de Morocoy	Turner 1974; 1978a; 1978b; Harrison 1977; 1978; 1982; Turner and Harrison 1978; Siemens 1978; Gliessman et al. 1983; 1985
35	Bajo Acatuch	Harrison 1977; 1978; 1982; Siemens 1978; Turner and Harrison 1978
36–39	Northern Belize	Siemens 1982b; 1983b
36	Cerros	Freidel and Scarborough 1982; Scarborough 1983a; 1983b; 1986; Crane 1986
37	Nohmul	Hammond 1983; 1985; Hammond et al. 1985; 1987
38	Albion Island	Olson et al. 1975; Olson 1977; Puleston 1977a; 1977b; 1979; Siemens 1977; 1982b; 1983b; Antoine et al. 1982; Bloom et al. 1983; 1985; Pohl 1990; Pohl et al. 1990
39	Pulltrouser Swamp	Turner and Harrison 1981; 1983; Turner 1986; Harrison 1990
40	Cobweb Swamp	Jacob 1992
41	Lamanai	Lambert and Arnason 1983; Lambert et al. 1984; Lambert 1985
42	Norlands Farm	Kirke 1980
		<u>Maya Highlands</u>
43	Quezaltenango	Wilken 1971; 1987
44	Almolonga	Wilken 1971; 1987
45	Panajachel	Mathewson 1984; Wilken 1971; 1987
46	Antigua	Wilken 1971; 1987

^alocation numbers cross-reference to Figures 1 and 5–14.

the south. Vestigial wetland fields occur in *bajos* and in the backswamps of streams along the western and eastern flanks of the peninsula (Figure 1).

Owing to scholarly fascination with the Maya civilization that emerged, atypically, in a humid tropical lowland (Mathewson 1977; Turner 1986) and that offers a diachronic perspective on such global-change processes as deforestation, interpretation of several aspects of the data remains controversial. The main debates turn on the spatial-temporal distribution of wet-

land agriculture in the Maya Lowlands and the relative significance of these intensive agroecosystems (*vis-à-vis* shifting agriculture) for the emergence and decline of urbanism and statism and of corollary environmental change during the Classic period. Siemens and Puleston (1972) first documented wetland agriculture in backswamps along the Río Candelaria on the western flank of the Maya Lowlands, thereby supporting a precocious hypothesis (Palerm and Wolf 1957:28) and challenging the validity of the prevailing shift-

Figure 5. Tenures of intensive wetland agriculture for locations with chronological data. Sources: Table 1; for climate, see text; for periodization, see Porter Weaver 1981: back endpapers.

ing-cultivation paradigm. Problematically, however, the dominant Mayan settlements and the highest population densities occurred in the core of the karstic peninsula, far from the major surface streams and surrounded by seasonally wet *bajos* (Puleston 1978; 1979).

In an effort to test the hypothesis that wetland fields also occurred in *bajos* in the environs of Tikal and other dominant settlements, Adams and colleagues employed airborne synthetic aperture radar. They estimated that the southern half of the Maya Lowlands contains some 125,000–250,000 ha of vestigial field complexes (Adams 1980; 1982; Adams et al. 1981). Subsequent research has not sustained

these high estimates (Pope and Dahlin 1989; 1993; Dunning n.d.; Dunning et al. 1991); nor are sizable hectareages evident anywhere in the core of the peninsula (Dahlin 1979; Dahlin et al. 1980; but see also Adams et al. 1990; Adams 1991; 1993).

Other researchers, meanwhile, documented wetland fields in *bajos*, as well as along streams, on both flanks of the peninsula. Vestigial wetland fields were initially identified through low-altitude aerial photography and ground survey (Siemens 1982b; Turner 1974), and subsequent excavations (Gliessman et al. 1983; Pohl 1990; Turner and Harrison 1981) refuted protests that ground patterns in *bajos*

were naturally forming gilgai (Puleston 1978; Sanders 1979). Harrison's claim (1977) that Bajo Acatuch contains the largest extent of field vestiges in Mesoamerica remains unsubstantiated, however. While Harrison maintains that his published photographs "clearly show broad patterns of grid-like variation in the vegetation . . . [which] . . . compares favorably with . . . [that] shown in photos published by Siemens and Puleston [1972] . . . and identified by them as various forms of raised fields [i.e., intensive wetland fields]" (Harrison 1977:477), such distinctive patterning is not readily evident. The equivocal nature of the evidence from these aerial photographs and the lack of ground survey and excavation notwithstanding, Harrison estimates some 24,610 ha of canals and planting surfaces for Bajo Acatuch (Harrison n.d., personal communication, as cited in Denevan 1982:Table 1). Even granting their existence, a dot planimeter measurement of Harrison's map reduces the figure to a maximum of 18,400 ha (1978:Figure 13.1), and Turner (1974:121) reduces it to just 12,000 ha.

The Maya Highlands

The Maya Highlands offer much less evidence of wetland fields than do the adjoining lowlands. In this series of highly dissected mountain ranges lying between the Maya Lowlands and the Pacific coastal plain, the climate generally is temperate with a short winter dry season. The known wetland fields are located in a series of volcanic basins near the settlements of Quezaltenango, Almolonga, Antigua (Wilken 1971), and Panajachel (Mathewson 1984). The last are "*chinampa*-like *tablones*," a regionally specific form of irrigation terrace. The antiquity of the Maya Highland fields remains uncertain, but both Wilken (1971) and Mathewson (1984) have suggested Prehispanic origins.

Analysis: Distribution, Hectareage, Morphometry

Distribution

Figure 1 maps known instances of intensive wetland fields. Figure 5 displays the tenures of

the 22 cases with chronological data; see also Figures 6–10. In eight of these 22 cases, the chronologies are based on nothing more than surface ceramics and the chronologies of nearby (and presumably contemporaneous) settlements. The remaining 14 cases are dated through excavation of the fields themselves, with 7 of these employing radiocarbon dating. The most rigorous chronologies pertain to Etzatlán, Teuchitlán, Xaltocan, Tenochtitlán, Iztapalapa, Xochimilco-Chalco, Amalucan, Estero de Tres Bocas, Río San Juan, Edzná, Río Candelaria, Cerros, Nohmul, Albion Island, and Pulltrouser Swamp. But that rigor is relative owing to the difficulties of dating agricultural features. Even some of these "rigorous" chronologies span long periods when fields *might* have been in use; such is the case for Etzatlán, Teuchitlán, Xochimilco-Chalco, Amalucan, Río Candelaria, Albion Island, and Pulltrouser Swamp. Most provisional are the chronologies of the fields at Teotihuacán, Eastern Texcoco, Puebla-Tlaxcala, Río Tecolutla, Río Azul, Bajo de Morcoy, and Cobweb Swamp, while the chronologies of the fields in the Southern Highlands and the Maya Highlands are unknown.

The spatial distribution of fields reveals the Mesa Central, the Maya Lowlands, and the Gulf Coast as regional nodes of wetland agriculture (Figure 1). Significantly, these subregions also served as the loci for the emergence of Mesoamerican sedentism, urbanism, statism, and corollary environmental changes. However, while in the Mesa Central the densest distribution of fields occurs in the environs of the dominant settlements, that is not the case in the other two subregions. Vestigial fields are located some distance from the dominant settlements of the Olmec along the Gulf Coast and Maya in their Lowlands (Figures 6–8). This lack of association may reflect the need for further research. The recent identification of vestigial fields in the Etzatlán and Teuchitlán basins may be a harbinger of future discoveries. More persistent exploration might reveal that fields became buried by sedimentation associated with environmental disturbance around major population nodes. Conversely, the absence could reflect that populations such as the Olmec sustained themselves with extensive agroecosystems alone (Coe and Diehl 1980:144–147).

The temporal distribution of wetland fields

Figure 6. Locations of intensive wetland agriculture and dominant settlements during the Preclassic period (2500 B.C. to A.D. 1) for locations with chronological data. Sources: Table 1; Base map: Porter Weaver 1981: Map 1; for settlement, see Blanton et al. 1981; Hammond 1990; Porter Weaver 1981.

reveals their already widespread use during the Preclassic emergence of agricultural sedentism and incipient urbanism (Figures 5–6). Current evidence suggests that the earliest fields were located in the Mesa Central at Amaluca—lending substance to provisional indications of early fields in the Xochimilco-Chalco subbasin, only some 100 km to the west. The Mesa Central might also have sustained other fields, at Teotihuacán and in the Puebla-Tlaxcala Basin, by the last millennium B.C. The Maya Lowland fields at Albion Island and Cobweb Swamp suggest similarly early origins. Along the Gulf Coast, the as yet limited data indicate that fields may not have been present until the first millennium A.D.

Extant fields are confined to the highlands (Figure 10). While exact figures on the extent

of fields in the Maya Highlands and Southern Highlands are lacking, the preponderance of extant fields occur in the Mesa Central. The Basin of Mexico contains a large area of extant *chinampas* in the Xochimilco-Chalco subbasin and a smaller area of wetland fields at Teotihuacán. The extent of the former is steadily decreasing, however, owing to urban expansion and hydrological changes. For example, the fields at Iztapalapa yielded to urban sprawl in 1981. Large but unspecified areas of extant fields also occur in the Puebla-Tlaxcala Basin, with smaller areas in the Teuchitlán, Toluca, and Huamantla basins.

Extant fields are absent from the lowlands, where only vestiges remain of a once intensively cultivated landscape. Most of these fields suffered abandonment centuries before Euro-

Figure 7. Locations of intensive wetland agriculture and dominant settlements during the Classic period (A.D. 1 to 900) for locations with chronological data. Sources: Table 1; Base map: Porter Weaver 1981: Map 1; for settlement, see Blanton et al. 1981; Hammond 1990; Porter Weaver 1981.

peas introduced the Old World diseases that resulted in population declines of as much as 90 percent (Denevan 1992). Only at one site, Río Candelaria, does the timing of field abandonment coincide with European invasion.

The lengthy tenure of wetland agriculture in some subregions—perhaps as long as three millennia in the Basin of Mexico and two millennia in the Maya Lowlands—suggests sustainability and applicability to current development efforts. But that many fields survive only as vestiges (and have been so for centuries) has led some scholars to suggest the opposite: that the nonsustainability of wetland agriculture might have contributed to the late-Classic depopulation of the Maya Lowlands (Atran 1993). If the reasons for the abandonment of these fields remain unclear—whether environmental

degradation linked to intensive agriculture, changing cultural context, depopulation, or changing perceptions—so too have been the benefits of reinstating wetland agriculture in lowland regions. These efforts have required high inputs of fertilizers and insecticides in order to achieve acceptable yields (Gómez-Pompa 1978; Gómez-Pompa et al. 1982). However, these results may well follow from the imposition of agroecological models based on practices in extant highland fields upon lowlands which are environmentally, culturally, and economically distinct (Chapin 1988).

Less controversial is the association between intensive wetland agriculture, terracing, and canal irrigation (Figure 11). The conjunction of wetland fields and terracing is evident in the Basin of Mexico, the Puebla-Tlaxcala Basin, the

Figure 8. Locations of intensive wetland agriculture and dominant settlements during the Postclassic period (A.D. 900 to 1521) for locations with chronological data. Sources: Table 1; Base map: Porter Weaver 1981: Map 1; for settlement, see Blanton et al. 1981; Hammond 1990; Porter Weaver 1981.

central Gulf Coast, San Antonio Arrazola in the Southern Highlands, Panajachel in the Maya Highlands, and the eastern Maya Lowlands. Canal irrigation is similarly widespread, save in the Maya Lowlands. Although the chronologies for terracing and canal irrigation often are tenuous, both begin as early as the last millennium B.C. (Donkin 1979; Doolittle 1990). In some places, vestigial wetland fields, terraces, and canal irrigation are closely juxtaposed. Along the Arroyo Naranjillo in central Veracruz, for example, sloping-field terraces overlook wetland fields just to the south of a putative canal irrigation system at Zempoala (Doolittle 1990:113–114; Sluyter and Siemens 1992). Yet the contemporaneity of these agroecosystems is uncertain. These vestigial conjunctions may

represent either different periods of intensification and disintensification as agricultural emphases shifted between piedmont and backswamp (a temporal interrelationship); or an integrated system of wetland and canal-irrigated fields that provided dry-season crops as complements to the wet-season crops of the terraced fields (a spatial interrelationship). Modern agricultural practice suggests the possibility of more complex ecological interrelationships as, for example, those deployed by some farmers in central Veracruz who employ wetland seedbeds for germinating maize subsequently transplanted to the piedmont at the beginning of the wet season (Siemens 1990). This strategy, in part, advances growth far enough by transplanting time in May to ameliorate the

Figure 9. Locations of intensive wetland agriculture and dominant settlements during the Historic period (A.D. 1521 to 1994) for locations with chronological data. Sources: Table 1; Base map: Porter Weaver 1981: Map 1.

worst effects of the *canícula*, the August dry period, which typically lasts for one to two weeks (Sluyter 1990:58–59).

Similar ecological relationships may have existed between the Xochimilco-Chalco subbasin and the adjacent piedmont (Parsons 1991:34). Also, the wetland fields at Panajachel, though less than 0.1 ha in extent, constitute part of a much larger terrace and canal-irrigation agroecosystem (Mathewson 1984) and suggest ecological interrelationships that may have been even more significant in the past.

Hectareage

Some of the hectareage estimates (Figure 12) remain tentative and necessitate maximum and minimum figures. Allowing the maximum

figures and employing 75 percent as the ratio of field surface to total complex area (see sources in Table 1), the Maya Lowlands account for the largest hectareage of wetland fields—more than 22,900 ha. The Mesa Central follows with some 11,850 ha, but this figure includes neither the Puebla-Tlaxcala fields nor those surrounding the Aztec capital of Tenochtitlán, both of unknown extent. Discounting the still dubious Bajo Acatush fields, the Maya Lowlands would follow the Mesa Central with 9,100 ha. The Gulf Coast follows both with 1,650 ha in central Veracruz (locations 25–28) and several thousand potential but still unspecified hectares to the north and south. Not many data are available for the Maya Highlands and Southern Highlands but hectareages there seem to be minimal.

The populations such hectareages could

Figure 10. Locations of extant intensive wetland agriculture and dominant settlements. Sources: Table 1. For base map see Porter Weaver 1981: Map 1.

have supported are relatively small. Based on maize yield and consumption for extant *chinampas* in the Basin of Mexico (Sanders et al. 1979:373, 380, 390), wetland fields might have supported as many as 19 persons/ha/year under single cropping where winter frosts obtain and 28 under double cropping (Denevan 1982:Table 1; Turner and Harrison 1983:Table 13.2). Even accepting these liberal estimates and assuming contemporaneity, the 9,100 confirmed hectares on the flanks of the Maya Lowlands could have fed no more than 255,000 persons per year. Meanwhile, the Classic-period settlement pattern was centered on the core of the peninsula: populations there increased from some 350,000 in A.D. 300 to about 1,500,000 in A.D. 800 (Turner 1990:Table 15.3) and achieved densities as high as 1000 persons/km² at the dominant settlements in the Petén such as Tikal (Santley et al. 1986:Ta-

ble 1). The only evidence thus far for fields in the core is for just 15 ha at Río Azul (Figure 12); and these fields, along with the small hectareages at Cerros (ca. 1.5 ha) and Edzná (ca. 375 ha), ceased production during the Early Classic period, precisely when population densities in the Maya Lowlands increased most rapidly. Conversely, outside of the peninsula's core, the larger hectareages at the northern Belize complexes, Río Candelaria, and Bajo Morocoy probably persisted throughout much of the Classic period (Figure 5).

The small sustaining capacity relative to population and the apparent absence of intensive wetland agriculture at the core of Classic-period Mayan settlement implies that the importance attributed to wetland fields *vis-à-vis* the emergence of Maya urbanism (Adams 1980; Turner 1978c; Turner and Harrison 1978; 1979; Mathewson 1977) remains speculative

Figure 11. Distributions of terrace, canal irrigation, and intensive wetland agriculture zones. Sources: Table 1; Denevan 1992; Donkin 1979; Doolittle 1990; Mathewson 1984; Palerm 1961; Santley et al. 1986; Sluyter and Siemens 1992; Turner 1978b; Wilken 1987; Base map: Porter Weaver 1981: Map 1.

(Dahlin 1979; 1985; Dahlin et al. 1980; Fedick and Ford 1990; Pope and Dahlin 1989; Sanders 1979). That shifting agriculture alone could not have supported such large urban populations as, for example, the 50,000 estimated for Classic-period Tikal (Turner 1990:Table 15.2) suggests four possibilities: 1) current understanding of Maya population geography is relatively immature (Culbert and Rice 1990), and the main population growth and impetus for Classic-period florescence occurred toward the eastern flank of the peninsula (Turner 1994); 2) wetland fields might have existed in the *bajos* surrounding Tikal and other settlements, but the vestiges of these fields have been obscured by post-abandonment aggradation (Scarborough and Gallopín 1991); 3) significant long-distance staple transport from

fields on the flanks of the peninsula to core settlements might have occurred (Sluyter 1993); and 4) other subsistence strategies supported the dominant settlements (Wilken 1971), e.g., systemic management of micro- and mesoscale environmental variation in the form of agroforestry (Atran 1993; Sluyter and Siemens 1992).

In contrast, the propinquity of wetland agriculture and dense population is certain in the Basin of Mexico. The Aztec capital of Tenochtitlán had a population of some 300,000, just one of several large cities in the Basin of Mexico (Sanders 1976b:Table 4.9). The 9,000 ha of wetland fields at Xochimilco-Chalco could have fed some 171,000 persons per year. Despite Palerm's (1973) and Calnek's (1972) seminal research, the extent of the fields surround-

Figure 12. Hectareages of intensive wetland agriculture for all periods for locations with relevant data. Hectareage shown is for field surfaces only, about 75 percent of the total area of the fields and canals. Sources: Table 1. Base map: Porter Weaver 1981: Map 1.

ing Tenochtitlán remains an estimate based on basin hydrology. They certainly were of an equal order of magnitude as the Xochimilco-Chalco fields. Clearly, the *chinampas* fed a large proportion of the Basin's inhabitants. Yet, the Aztecs created a vast tribute domain based on their sustained ability, ultimately, to produce agricultural surpluses. A fuller understanding of how will require many more data on wetland field distribution and hectareage.

Morphometry

Understanding of morphometric variation (Figures 13 and 14) remains quite provisional given the frequent necessity of relying on published photographs and diagrams rather than

explicit statements. Nonetheless, four tentative spatial-temporal associations emerge.

The first of these is that field length, width, and amplitude tend to increase through time, most clearly seen in the Mesa Central subregion, but evident panregionally. For example, the width of Iztapalapa fields extant till 1981 exceeds the width of vestigial fields in a ratio of 4 to 1. Similarly, the Mesa Central fields having tenures through the Postclassic and Historic periods tend to be larger than Maya Lowland fields which persisted only to the Early Postclassic. The evidence is not definitive, however. The small size of fields at Tenochtitlán during the Postclassic period may indicate that large fields did not emerge until the Historic period; hence, the putative trend may be an artifact of still imprecise chronologies.

Second, fields with linear-curvilinear, biaxial patterns are confined to the Gulf Coast, and, more specifically, to backswamp contexts. Siemens (1983a) has proposed a model that may account for this correlation. He argues that this morphology enabled farmers to regulate drainage at the end of the wet season in such a way that they could plant as early as possible and still retain sufficient water for splash and subirrigation later in the dry season. In the absence of large dams, such a strategy required a labyrinthine canal system punctuated by small dams. The resulting curvilinear morphology contrasts sharply with the linear, uni- and biaxial forms of the Mesa Central lake basins, where subirrigation in conjunction with large dams for controlling water levels and salinities was more critical than drainage (Palerm 1973).

Third, the distinctive morphology of amorphous, radial fields at Edzná in the Maya Lowlands is unique, probably due to their local geological context. Edzná sits in a *polje*, and the canals may be modified grikes: limestone joints which are widened by solution and sometimes display a radial plan (K. W. Butzer and W. E. Doolittle 1991, personal communication based on a 1987 reconnaissance of Edzná).

Fourth, amorphous shape and irregular pattern only occur in the Maya Lowlands. This association may reflect that the tenure of these fields ended during the Classic and Early Postclassic periods. Elsewhere, as for example in the Mesa Central, field reworking during the Postclassic and Historic periods may have obliterated earlier amorphous fields. Alternatively, this shape and pattern may relate to *bajo* hydrology rather than technological elaboration.

These patterns suggest more specific and therefore more speculative relationships between morphometry and environment, function, crops, economy, and culture. Flat-profile fields, for example, might have facilitated splash irrigation by minimizing runoff and maximizing infiltration. Cambered-profile fields, in contrast, would have facilitated runoff and drainage, although they are not apparent in the record, possibly due to post-abandonment erosion and sedimentation. Also, a tension would have existed between spatial and subirrigation efficiency. Low frequency systems with wide fields and narrow canals would have poor irrigation characteristics but premium

planting-surface-to-canal ratios—possibly an association with surplus production, high population density, or humid climate.

Certainly the environmental context of extant and vestigial fields varies greatly: from hot climates with no dry season to semiarid climates with cool summers; from streams to basins to springs; and from elevations of 2,500 m to near sea level. But the precise nature of these environments during Prehispanic times remains uncertain. Only the coarsest changes in late-Holocene climate, vegetation, and hydrology are as yet apparent. The evidence from glacial (White 1981; 1986; Heine 1984a; 1984b), lake-level (Bradbury 1971; 1989; Limbrey 1976; Watts and Bradbury 1982; Street-Perrott et al. 1985; Flores Díaz 1986), and pollen records (Graham 1973; Dahlin 1983; Brown 1985; Vaughan et al. 1985) does not correlate particularly well. Nonetheless, these records do provide a general regional climatic sequence: a warmer, drier period than present during the middle Holocene; a cooler, wetter period ca. 1500 B.C. to A.D. 1; a general drying trend since A.D. 1; and interruptions of that trend by cooler, wetter periods ca. A.D. 500–1000 and ca. 1400–1850 (Figure 5). Apparently then, agricultural intensification—including that in wetlands—began during the onset of a cooler, wetter climate ca. 1500 B.C. This conjunction may reflect greater reliance on agriculture during a period of climatic and cultural dynamism, although these linkages remain unclear. The ensuing expansion of wetland agriculture during the Late Preclassic-Early Classic transition correlates with the onset of a drier climate, ca. 250 B.C. to A.D. 250. Agricultural expansion at this time occurred in the Mesa Central and the Maya Lowlands, with diffusion to the Gulf Coast. Drier climates might have resulted in greater reliance on wetlands which would have offered both crop security in the face of increasingly uncertain precipitation regimes and increased yields. Initial success in securing crop security furthermore might have stimulated urbanization and population increase in the Classic period on the basis of higher yield.

If a sophisticated understanding of the constructions and functions of wetland fields continues to be elusive, two main interpretations have emerged in the Maya Lowlands. Some researchers favor explanations of construction that are based on field raising through the importation of sediments to raise planting plat-

Figure 13. Morphologies of intensive wetland agriculture for all periods for locations with relevant data. Sources: Table 1; Figure 4; Base map: Porter Weaver 1981: Map 1.

forms between canals in *bajo* contexts (Puleston 1977b; Turner 1983b; 1991), implying a subirrigation function similar to the *chinampas* of the Basin of Mexico. Other researchers favor channelization with little or no field raising (Pohl et al. 1990), implying a drainage function similar to flood-recessional agriculture. Critiques of the first interpretation note that the origin of calcareous mottles evident in field profiles at Pulltrouser Swamp is natural and therefore not evidence of field raising (Pohl et al. 1990:226). While such criticism has led to revision of the “field-raising hypothesis” (Turner 1993a; 1993b), the discovery of a bi-face pick within the mottled stratum does indicate human disturbance and the possibility of some field raising, perhaps using canal spoil rather than imported sediments (Turner and Harrison 1983:41–42, 47; Turner 1991). Reconciliation of these opposing interpretations will

hinge on new data and likely—given the morphometric variety thus far evident—will reveal that construction and function differed with environmental, economic, and cultural context.

An alternative approach to investigating construction and function has been the experimental one. The construction of fields for food production (Gómez-Pompa et al. 1982) and for understanding Prehispanic practices (Puleston 1977a; 1977b) has yielded limited data thus far. Relying on historical descriptions of *chinampa* construction in the Basin of Mexico (West and Armillas 1950), experimenters have constructed raised planting platforms out of sediment and vegetation. These field experiments have yielded information on construction inputs and crop productivity. In addition, controlled experiments have focused on specific aspects of function, such as nitrogen and

Figure 14. Dimensions of intensive wetland agriculture for all periods for locations with relevant data. Sources: Table 1; Base map: Porter Weaver 1981: Map 1.

phosphorous cycling. The experimental evidence supports the hypothesis that the periodic transfer of bottom sediments from canals to field surfaces, or "mucking," was an integral element of intensive wetland agriculture (Vasey 1983; Vasey et al. 1984). In addition, planting surfaces subject to annual flooding would receive nutrient inputs through sedimentation as well as pest and weed control through submergence (Thurston 1990).

The crops grown on Prehispanic wetland fields remain largely unknown. Direct evidence from excavations is scanty. Sixteenth-century ethnohistorical materials for the Basin of Mexico provide some insights for the last centuries of the Prehispanic period. Maize (*Zea mays*), squash (*Curcubita* spp.), beans (*Phaseolus vulgaris*), amaranth (*Amaranthus* spp.), sage or *chía* (*Salvia hispanica*), chile (*Capsicum an-*

num), tomato (*Lycopersicon esculentum*) and green tomato (*Physalis ixocarpa*) were the major crops (Rojas Rabiela 1983b; 1991; Torres 1985). But little is known about crops grown during earlier time periods. In the lowlands, although plant micro- and macrofossils from field excavations confirm only maize (Turner and Miksicek 1984), a series of hypotheses focus on cacao (*Theobroma cacao*), amaranth (*Amaranthus* spp.), cotton (*Gossypium hirsutum*), squash (*Cucurbita moschata*, *C. pepo*), and beans (*Phaseolus* spp.).

The Tasks Ahead

On the one hand, the database has grown large enough to demand a systematic analysis. On the other hand, the lacuna reflect the lack

of a coherent research strategy and prevent a more sophisticated analysis and synthesis. Idiosyncratic research priorities and strategies have resulted in data of uneven quality with respect to field chronology, hectareage, and morphometry. Yet, while these data are an insufficient basis for an authoritative synthesis, they do permit provisional identification of significant variables, spatial and temporal trends, and a series of testable hypotheses that may lend coherence to further research. Four such hypotheses address the themes of the introduction:

- (1) The emergence and broad distribution of wetland agriculture during the Preclassic period suggests that farmers built wetland fields wherever and whenever social processes elicited dense population nucleations and hydrology was appropriate. Testing this hypothesis will require more sophisticated and persistent prospecting, particularly in the backswamps of the Olmec realm and the *bajos* in the core of the Maya Lowlands.
- (2) The propinquities of intensive wetland agriculture and terracing, canal irrigation, and extensive agroecosystems in time and space suggest that their emergence was ecologically interrelated. Testing will require detailed studies of cases in which these agroecosystems are juxtaposed and in which chronometric controls permit analysis of the interrelationships among crops, environments, and anthropic environmental impacts.
- (3) The morphometric variety of wetland fields reflects the environmental and social contexts of landforms, hydrology, population density, levels of taxation and tribute, and the centralization of decision making. Evaluating the relative importance of these contexts will require comparable morphometric data from a large sample of field complexes in the various subregions of Mesoamerica.
- (4) The long tenure of wetland agriculture in some locations implies a productive and sustainable agroecosystem that holds promise for transforming social and ecological relations (cf., Browder 1989; Kropotkin 1919; Parsons 1985). Testing will require a refined chronology of the venerable Xochimilco-Chalco fields in order to

establish origins, continuities, and transformations in relation to dynamic environmental and social contexts.

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Notes

1. A more detailed, monographic version of this paper, intended to complement Donkin (1979) on terracing and Doolittle (1990) on canal irrigation, is in preparation.
2. Three forthcoming publications (Adams n.d.; Rice n.d.; Turner n.d.) should provide significant new data and interpretations.

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Sluyter, Andrew. 1994. Intensive Wetland Agriculture in Mesoamerica: Space, Time, and Form. *Annals of the Association of American Geographers* 84(4):557–584. Abstract.

Geographers have led the effort to better understand Prehispanic, intensive wetland agriculture (“raised fields”) in Mesoamerica. An overview of that literature provides the database for a subsequent spatial-temporal analysis and a resource for primary research. The analysis employs maps to identify changing relationships among distribution, hectareage, and morphometry in order to address wetland agriculture’s role in the emergence of sedentism, urbanism, statism, and corollary environmental change; its interrelationships with other agroecosystems and ecological parameters; and its productivity and sustainability. The result is a modest benchmark in the research process which identifies significant variables, putative patterns, and several testable hypotheses, namely 1) that wherever social processes elicited dense population nucleations and hydrology was appropriate, farmers built wetland fields; 2) that the emergence of intensive wetland agriculture was ecologically interrelated with terracing, canal irrigation, and extensive agroecosystems; 3) that morphometric variation among wetland fields reflected contextual variables of hydrology, population density, taxation, and centralization of decision making; and 4) that intensive wetland agriculture in Mesoamerica was a productive and sustainable agroecosystem. **Key Words:** agroecosystems, intensive wetland agriculture, Mesoamerica, Prehispanic, raised fields.