Man, Fire and Wild Cattle in North Cambodia

CHARLES H. WHARTON

Georgia State College,
Atlanta, Georgia

About 500 years ago a civilization whose art and architecture has been said to dwarf the wonders of Egypt, Greece and Rome laid down its arms and entered a non-martial and non-material period of its history. In so doing much of the environment that once supported its immense cities and armies was abandoned to a few scattered villagers who, with the aid of the agency of fire, have since maintained this depopulated island of northern Cambodia as one of the last great refuges for herbivorous mammals in all of southeast Asia.

In the far reaches of this small Asian kingdom can be found a remarkable array of wild hoofed ungulates. Here, one can observe herds of banteng (*Bibos sondaicus*), gaur (*Bibos gaurus*), water buffalo (*Bubalis bubalis*) and two rare species approaching a critical minimum in southeast Asia, the kouprey (*Novibos sauvelli*), and the Eld's deer (*Cervus eldi*).

Through the patient work of Harold Jefferson Coolidge, there is now worldwide interest in the kouprey, Cambodia's unique wild ox, considered by Coolidge (1940) to be one of the most primitive of living taurines and a surviving remnant of a mid-Miocene form, ancestral to both the wild and domestic cattle of modern times. It has been my privilege to participate in two studies of the wild cattle, both inspired by the urgent need to evaluate the status of the kouprey both ecologically and biologically.
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In 1951-1952 the Coolidge Foundation sponsored the Forest Cattle Survey Expedition to southeast Asia which, under the handicap of Viet Minh operations, conducted a brief survey of the ecology of the kouprey.

In 1963-1964 the Joint Wild Cattle Research Program of the Royal Cambodian Government and the Pacific Science Board was again hindered by political difficulties which eventually terminated research and left the main objective, the capture of a nucleus herd of kouprey, in the hands of a Cambodian Team under the able direction of Mr. Ou Kim San of the Cambodian Game Department.

While making observations on wild cattle during the course of the latter mission, I became interested in the ecological factors linking men and wild cattle. Through the work and interest of E. V. and Roy Komarek, I became aware that studies on wild cattle must seriously consider the effects of fire. Since fire is one of the earliest and foremost natural agents which man has used to modify his environment, the ecology of man assumes importance. Thus do men, fires, and wild herbivores become important components in the ecology of the savanna forests of southeast Asia.

CAMBODIA AND THE TROPICAL FOREST BIOME

There are few, if any, published reports on Cambodian environments in the western world. This paper seeks to summarize observations I have made during two dry season visits to Cambodia (Fig. 1) and to relate these observations to other studies in southeast Asia and elsewhere. It is a hopeful attempt to present a more unified picture of the impact of man and fire on the biota of northern Cambodia.

Since fire ecology forms a central theme a brief introduction to the Cambodian environment and its position in the tropical forest biome is necessary.
Physiography

The Kingdom of Cambodia comprises 181,035 square kilometers of predominantly flat or rolling terrain bordered by Thailand, Laos and Viet Nam. Twenty per cent of its coastline fronts the China Sea. Figure 1 indicates the major physiographic divisions of Cambodia.

Extensive alluvial flood plains border the Mekong River and Tonle Sap Lake at elevations between 5 and 30 meters, much of which receive an annual increment of silt. This riceland along with the plentiful fish of the great lake and river, and a population of
The lowest temperature on record is 9.0°C. at Stung Treng in January, 1937, the highest 41.0°C. at Battambang in April, 1958.

Soils

Some soils underlying the savanna forest regions of Cambodia are composed of ancient alluvial and colluvial deposits but, in general, they are a mixture of lithosols and plinthite podzols with grey hydromorphic and alluvial clays in depressions and low areas, sometimes underlaid by infertile acid shales east of the Mekong.

The lithosols are pedologically new erosion products of the decomposition of sandstone, shale or granite. More common in the wild cattle habitat are the plinthite podzols stretching from the Vietnamese border on the Srepok River to Kratie and Laos and across the northern halves of the provinces of Kamppong Thom and Siem Reap. They are the result of continued leaching and erosion in a monsoon climate of ancient red-yellow podzols (laterites) with severe oxidation of iron and aluminum in the B horizon often resulting in abundant laterite concretions. If abused they may form a porous but hard ironstone or “cuirass” as has covered many square miles of Nigeria and Dahomey in Africa, and at Iata in Brazil, McNeil (1964). Phillips (1959) indicates that similar ironstone gravels occur in Africa with an alternation of regular wet and dry periods. If reforested, reversion may occur and Keat Chantha of the Cambodian Forest Service indicated that these lateritic soils changed markedly under the influence of humic acid beneath denser forest and suggested that preck (Arundinaria ciliata) was a pioneer stage in reversion, followed by the Khlong-Tabeng complex of dipterocarps (Fig. 2).

The effect of fire on the soils of the northern plains has been expressed by USAID-CFS (1963): “approximately 80% of the area is burned over annually, depleting the fertility, as the minerals, converted to ash, are easily dissolved and carried away in the rainy season runoff waters. On the extensive infertile northern plains these fires have resulted in severe impoverishment of land which, at its best is naturally poor and infertile.”

It is my opinion that this statement is applicable only in a general
sense. The first rains in April are in the nature of passing showers and have little runoff effect. Thus, the rains of April and early May may make the ash available to much of the plant life, particularly in the sandy soils of the arid savanna forests. Much other ash is, of course, carried towards or into local depressions many of which are linear, open grasslands often one kilometer in length (perhaps representing ancient rice terrain) and into waterholes. It would appear that in these lower areas the new grass might utilize some of the ash materials where it stands for days without runoff. Later, with massive inundation it is easier to understand the complete loss of surface material.

One of the most striking things about Cambodian soils is the apparent absence of the organic horizon. Litter and humus are rapidly destroyed under the conditions of heat and moisture beneath dense forest. In more open or savanna forest, fire may remove much of the vegetable material which would go to make up the organic upper layer of the A horizon. In Thailand, Ogawa et al. (1961) observed that fire was most frequent in savanna forest in the early part of the dry season when trees had lost about ¼ of their leaves. In one stand their estimate of the annual litter on
one hectare was 4.9 tons of leaves, 1.5 tons of branches, and 0.7 tons of grass shoots. They further estimated that 0.07 ton/ha/year of nitrogen is regularly lost from savanna forest by burning litter and ground flora (the figure for temperate grassland is 0.14-0.19 ton/ha/year). These authors found that the organic carbon content at soil surface is lowest in savanna forest (about 0.50 ton/ha) and double this in gallery forest. The total leaf area of gallery forests in Thailand appeared to be four times that of the savanna forests.

Vegetation

While certain wild cattle, such as the gaur, may occur throughout Cambodia in the areas wherever there is a combination of humid forest and glades, and banteng are known from most of the provinces of Cambodia; the plains areas (Fig. 1) are the principle wild cattle lands. Since our studies have dealt with the northern plains, my discussion deals primarily with this area.

Classically, the forests of southeast Asia are known as “monsoon forests” spreading from northeast India as far as Java and northern Australia. While Eyre (1963) considers the Cambodian coastal ranges and the Vietnamese cordillera as supporting a tropical rain forest climax, the climatic climax for most of Cambodia is apparently a sub-humid, semi-evergreen forest where the taller canopy members are deciduous and which Eyre would consider as tropical seasonal forest.

The most thorough and pertinent vegetation studies in the general area have been those conducted in adjacent Thailand by Samapuddhi (1957), the Thai Royal Forest Department (1962) and by Ogawa, Yoda, and Kira (1961). One of Thailand’s largest physiographic divisions is the Korat Plateau, an area as large as Cambodia west of the Mekong. The southern edge of this great plateau meets the northern frontier of Cambodia along the crest of the Dangrek Range. Its western edge is an even lower range of hills, but a well-marked boundary nevertheless. According to maps of the Thai Royal Forestry Department (1962) and Ogawa et al. (1961), the bulk of its vegetation must be quite similar to that of northern Cambodia. The Korat Plateau appears bordered on both the west and south by an unbroken belt of tropical evergreen forest con-
TABLE 2: CLASSIFICATION OF CAMBODIAN FOREST ASSOCIATIONS BY WHARTON, HAIG ET AL (FAO) AND USAID-CFS HOMOLOGIZED WITH VEGETATION IN THAILAND DESCRIBED BY SAMAPUDDHI, THE THAI ROYAL FOREST DEPARTMENT AND OGAWA ET AL, IN BURMA BY STAMP, CHAMPION, RICHARDS AND EYRE AND IN AFRICA BY PHILLIPS.

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<td>Highly humid to humid forest</td>
<td>Evergreen dipterocarp forest (Stamp) Sou. tropical wet evergreen (Champion) Tropical rain forest (Eyre)</td>
<td>Tropical evergreen forest</td>
<td>Tropical evergreen forest</td>
<td>Humid forest Wet evergreen forest</td>
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<td>Humid forest</td>
<td>Pyinkado or semi-evergreen forest (Stamp) Sou. trop. semi-evergreen forest (Champion)</td>
<td>Semi-evergreen forest</td>
<td>Tall deciduous forest Evergreen gallery forest</td>
<td>Semi-humid forest Moist deciduous forest</td>
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<td>Sub-humid wooded savanna to mild sub-arid wooded savanna</td>
<td>Dry teak forest or semi-Indaing (Stamp) Sou. trop. dry deciduous (Champion)</td>
<td>Deciduous dipterocarps forest</td>
<td>Mixed savanna forest Dipterocarp savanna forest</td>
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<td>Arid wooded savanna to sub-arid wooded savanna</td>
<td>Indaing (Stamp) Sou. trop. dry deciduous (Champion)</td>
<td>Deciduous dipterocarps forest</td>
<td>Dipterocarp savanna forest</td>
<td>Dry forest Dry deciduous forest</td>
<td>Arid savanna forest (2) Open parkland (1)</td>
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<td>Sub-humid wooded savanna (Rarely open grassland)</td>
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Continuous with that covering Cambodia's coastal ranges. This heavy forest in the south part of the Korat Plateau, which I have not seen, apparently lies chiefly on the gently dipping north slope of the Dangreks. Topographic sheets indicate a large number of springs and streams originating on the dip slope of these mountains and draining northward into the major east-west stream, the Mae Nam Mun River (now paralleled by a railroad). Stamp (1925) indicates a moist forest on similar dip slopes of porous sandstones in both the Mahodaung and Pondaung Ranges in Burma. In 1952 I did not observe much dense forest on the south or escarpment slope of the Dangrek range. In the region of the great ruins of Preas Vihear, northwest of Cheom Ksan, the savanna forest came nearly to the base of the escarpment.

The vegetation of the northern plains of Cambodia was originally described by Wharton (1957), who indicated that this area was largely “maintained as a sub-climax by the agency of fire.” Table 2 attempts to compare my present and past classification of the major tropical Cambodian vegetation types with other classifications made, in Cambodia, by Haig, et al. (1958), and the USAID-Cambodian Forest Service (1962); by Eyre in Burma (1963), and by Richards (1952) based chiefly on the prior work of Champion (1946) and Stamp (1925); by the Thai Royal Forest Department in Thailand (1962) largely following Samapuddhi (1957) and by Ogawa et al. (1961), and in Africa's bioclimatic regions as outlined by Phillips (1959).

Figure 3 indicates the approximate distribution of the major vegetation types of Cambodia, derived from personal observation and from maps of the Service Géographique du Cambodge and the U.S. Army Map Service. The limits of the sub-humid forest are the most tentative. It should be understood that many small outliers of sub-humid forest are not shown. While the boundary between savanna and sub-humid forest is often quite sharp, boundaries between the other types may not be so. Sub-humid forest should grade gradually into humid forest. The small isolated areas of conifers such as occupy the Kiririom plateau and the area north of Kampong Thom are not indicated.

My present terminology will, I hope, simplify comparison with
FIG. 3. Distribution of the major vegetation types of Cambodia. A, humid forest; B, sub-humid forest; C, savanna forest; D, hydrophytic communities; E, open savanna forest or savanna. Base map is Administrative and Road Map, scale 1:1,000,000, Service Géographique du Cambodge.

other areas of the world. Since the exact proportion of deciduous to non-deciduous tree species is so poorly known in Cambodia, terms connoting leaf loss have been avoided. The proportion of deciduous species appears to depend on the number of ecologically dry months as it does in Africa.

It should be understood that the area designated as savanna forest does not present a homogeneous vegescape. Within it, large and small areas of sub-humid forest appear as isolated patches (Fig. 4), or as gallery forest. Larger forest areas appear to be original climatic climax, which do not burn and which support a humid forest fauna quite distinct from that of the savanna forest. In Mondol Kiri province the road from Kratie passes through a magnificent sub-humid climax forest (Fig. 5), the tallest trees being deciduous, or nearly
so, even in late December and often bearing gigantic epiphytes (Fig. 6). There is, in December at least, an almost total absence of litter beneath this forest. The surface soil is underlain at .5 meters by a plinthite podzol with pisolitic iron nodules (Fig. 7), a soil characteristic of much of the savanna forest as well. Slash and burn agriculture and fire has led to the destruction and modification of these original forests (Fig. 8). The ecotone is often very narrow and distinguished by the fire resistant, white-trunked Sralao (*Lagerstroemia* sp.) (Fig. 9).

There are likewise areas of arid savanna forest (Fig. 10) seemingly under edaphic control, and glades and strip savannas in which either edaphic or cultural factors have reduced woody vegetation.

The bulk of the terrain is a tree-bearing savanna, presenting a more or less unobstructed view from either the ground or the air (Fig. 11). It shares species in common with three categories of Burmese forests as listed by Richards (1952). Chlek (*Terminalia tomentosa*) is one of the two most dominant species in both the open forests of Cambodia and the Dry Teak Forest of Burma. The
Cambodian savanna forest shares one dominant with the Burmese Semi-Indaing Forest, the peechuck (*Shorea obtusa*) and two others, khlong (*Dipterocarpus tuberculatus*), and reang phnom (*Pentacme siamensis*), which are only locally abundant in Cambodia. Cambodia’s savanna forest conforms with Eyre’s Indo-Malaysian Formation of the Deciduous Seasonal Forest widely represented from India to Java in the interior regions and rain shadows.

Table 2 does not list all forest categories in Thailand. The Thai Royal Forest Department (1962) notes a mixed deciduous forest with teak (*Tectona grandis*) in the north, and without teak in the south of Thailand. I observed some teak in dense Cambodian forests, but I saw few areas that directly compare with what is described in their study as “mixed deciduous forest.” The Thai study states that fires sweep the entire teak forest about March and April doing comparatively little damage to sound trees but “untold damages are done to fallen, unsound and hollowed standing trees and seedlings.”

The category “deciduous dipterocarp forests” is of great interest, for the bulk of northern Cambodia fits this Thai description. These
forests occupy from 70 to 80% of the total forest area of eastern Thailand and are thought to be due to edaphic factors “being found on porous, well-drained soil, ... generally formed by the decomposition of laterite.” According to the Thai (1962) study, “The forests are burnt over regularly every year; nevertheless, natural regeneration occurs fairly plentifully and often luxuriantly. The seedlings are burnt back every year but owing to the accumulation of food reserve in their root-stocks, they are able to send up more vigorous and bigger shoots each year. When the shoots are finally freed from the danger of fire, the seedlings are able to establish themselves and become part of the forest crop.”

The forests of the Korat Plateau have the principal species Pentacme siamensis, Shorea obtusa, Dipterocarpus obtusifolius and D. intricatus in common with northern Cambodia, but apparently lack one of the Combretaceae, Terminalia alata, so abundant in Cambodia. Much of the ground cover, such as the fire-resistant cycad (Cycas revoluta [=siamesis ?]), Dillenia and Holarrhena, appears to be common to both areas. The Thai study indicates that.
Fig. 7. Plinthite podzol showing numerous pea-sized iron concretions. Beneath climax sub-humid forest midway between Kratie and O Raing, Mondol Kiri province, eastern Cambodia. The lower limit of a weak A horizon at hand level is suggested.

Fig. 8. Montagnard village in the vicinity of Dalat, Viet Nam showing the extensive destruction of the original humid forest. These tribesmen of Indonesian descent occupy much of eastern Cambodia and in addition to shifting cultivation, hunt extensively with the crossbow and other primitive weapons.
as is true with much of the Cambodian savanna forest, "the predominant undergrowth is the grasslike bamboo, Ya Phet (Arundinaria ciliata)."

Except for terminology, the Ogawa, et al. (1961) study essentially agrees with the Thai Royal Forestry report. Dipterocarpus obtusifolius, Pentacme siamensis and Shorea obtusa are abundant in both the dipterocarp savanna forest and the mixed savanna forest categories of the Japanese authors, although they state that no distinct dominants are present in the latter. They recognize two distinct phases within the dipterocarp savanna forest, one a xeric Pentacme-Shorea phase, and a moister Dipterocarpus tuberculatus—D. obtusifolius phase. They indicate that these latter dipterocarps form pure stands where human disturbance is heavy, stating that ground fire is the most important biotic factor in the formation and maintenance of savanna forests, and that the two Dipterocarpus discussed above are especially fire-resistant "vigorously regenerating by . . . sprouts from stumps . . . thus . . . more abundant in secondary forests produced by human disturbance." They suggest that
forests observed along the Thailand-Cambodian highway may have originated in this way. Since this highway bisects a rather broad belt of supposedly climax evergreen forest the assumption is that the savanna forest in this sector is the result of human disturbance. Ogawa, et al. further point out that their category of “tall deciduous forest” (characterized by the presence of teak) formerly extended much farther southward, having been degraded successively through mixed savanna forest to the final dipterocarp savanna forest through ages of human disturbance. These observations thus support the thesis that most of northern Cambodia’s savanna forest is the result of human activity.

The question of the oft-dreaded cogon grass (*Imperator cylin­drica*) was brought to my attention by Hugh Popenoe (personal communication) who indicates that this grass is one of the principal reasons why agricultural lands under shifting cultivation are abandoned in Asia. In 1952 I recorded this grass near our camp at Koh Ker but I did not see it in our recent study area in Kampong Thom province. It does not appear to be a major problem on the soils of the wild cattle range. I suspect that it occurs more commonly on the richer and moister basaltic plateaus of eastern Cambodia. Certainly this apparent distinction between much of northern Cambodia and other areas of southeast Asia suggests that further investigation is needed.

The only figures on productivity of possible rough correspondence with Cambodia’s savanna forest are those of Ogawa et al. (1961) derived from Thailand savanna forest (mixed and dipterocarp). They estimated the standing crop to be about 55 tons/ha and the turnover rate of the living plant body at eight tons/ha.

THE HUMAN ELEMENT

If it is true that most of northern and eastern Cambodia is pre-climax vegetation maintained by periodic and purposeful fires set by man, and if we agree with Bartlett (1956) that the extent of grassland in normally forested tropical countries is a measure of the cumulative effect of man’s occupation, then the question of human ecology merits brief attention.
Fig. 10. Arid savanna forest showing the burned (foreground) and unburned condition of the short grasses and sedges which sparsely carpet the sandy soil. The tree (Dipterocarpus intricatus) and the tabeng (D. obtusifolius) are the dominant tall trees.

Fig. 11. Savanna forest on plinthite podzol near the Tonle Repou River in Kampong Thom province. The peechuck (Shorea obtusa) is the commonest dipterocarp. A herd of banteng (Bibos sondaicus) is partly concealed by the central clump of trees. This ground is extremely rough and nearly impossible to negotiate by vehicle.
FIG. 12. Savanna on the Chhlong Plateau near O Raing, Mondol Kiri province, eastern Cambodia. Originally humid climax forest occupied the plateau top but generations of Mnong with slash and burn agriculture have converted it to more or less permanent savanna. Fire is probably an important factor in preventing its reversion to some type of scrub.

FIG. 13. Associations within the hydrophytic community. This moist, flat terrain surrounds Cambodia's great lake (Tonle Sap) and occupies much of the Mekong Delta. Here rice is the dominant crop and ducks are raised. The skyline is dominated by the sugar palm (Borassus).
It is difficult to postulate when man first appreciably changed the face of Cambodian forests. Presumably there was little alteration by the mid-Pleistocene contemporaries of *Pithecanthropus* and the stone age Anyathian culture of Burma. Burling (1965) indicates a continuous drift of peoples into Cambodia from the west and north during the Pleistocene, the general trend being that of mongoloid elements from the north which absorbed negrito and australoid predecessors. It is thought that the negritos dwelt in extensive riverine swamps and dense forests without permanent villages and were driven into the hills by later invasions where they still exist in a few isolated refuges. A wave of Indonesians is now represented by the famous elephant-hunting montagnards of the southern Vietnamese highlands. The Rhadé tribesmen, whom I visited in 1951, have only locally altered the heavy forest (Fig. 8). These mountain peoples have a low population, but given time, their slash and burn agriculture methods can strongly modify the forests, as seen from aerial photographs of the Kontum Plateau. These Mnong, as they are called in Cambodia, number 68,000 and inhabit the area from Stung Treng east to Djing in Viet Nam.

On the southern basaltic massif of the Chhlong Plateau (Fig. 1) slash and burn methods of the Mnong have long ago removed the mantle of heavy forest and formed a savanna grassland (Fig. 12). USAID soil scientists have said of the deep red latosol underlying these rolling grasslands, “the continuing habit of burning the grasslands continues to deplete these lands, which have undergone deterioration to such an extent that they are considered as an uneconomic producer of rubber, the usual land use of the “red lands” elsewhere in Cambodia.”

According to Butzer (1964), there is no evidence for or against advanced fishing and planting populations along the coasts and river valleys of southeast Asia during the last millenia of the Pleistocene. There is solid archeological evidence of 8000 years of agriculture in the Middle East, but hardly 2000 years of it appears to be known in southeast Asia. Two thousand years ago it is thought that the hill people were using slash and burn agriculture in Cambodia and that the lowland plains supported a reasonably dense population subsisting on wet rice cultivation. While invasion from the west apparently took two routes, one by the sea and the other down the Mun
River of Thailand, Groslier and Arthaud (1957) feel that the primary civilization was maritime in and near the lower Mekong Delta.

Between the 2nd and 6th century a powerful, Indianized state, Funan, occupied the delta and another state, Chenla, grew up in the middle basin of the Mekong. Large cities were present there in the 6th century. Between the 6th and 9th centuries according to Groslier and Arthaud (1957) the successive capital cities of the Khmer peoples shifted northward and “the cultivation of rice on the uplands became their main industry.” This is significant because at the present time rice is almost entirely cultivated in the hydrophytic lowland community again (Fig. 13).

Neither Briggs nor Groslier and Arthaud offer reasons for the desertion of the delta region. Perhaps the problems of living with the vast Mekong floods seemed more formidable than carving a more controllable irrigation system from the great plains stretching to the north.

In any event the formidable hydraulic civilization of the Khmer evolved, and as Wittfogel (1957) has emphasized, a governmental apparatus capable of immense hydraulic works can very conveniently be used to build huge palaces, tombs and monuments difficult to match by any other agrarian or merchantile society.

With the establishment of the capital city at Angkor (near Siem Reap) northern Cambodia became the center of a vast empire (Fig. 14) which stretched from the mountains of Viet Nam to the Menam River of Thailand. Northern Cambodia seems to have been the natural center for this civilization. Large cities flourished—Briggs (1951) has stated that Nero’s Rome could have been placed within the central portion of Angkor Thom alone. According to Groslier and Arthaud “Angkor . . . swarmed with people, with a population probably exceeding a million.” To sustain this population and its riziculture in the northern plains required a system of artificial lakes (baray), reservoirs and canals. Most were walled up, not dug. Some canals were 60 kilometers long. In my 1951 study area at Koh Ker (approximately 100 square kilometers) I noted three man-made reservoirs and during our recent study near the Laotian border two of these rectangular basins were regularly used by our field parties.

It is possible that the Khmers, by using reservoirs, canals and
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Fig. 14. Distribution of the Khmer civilization in northern Cambodia and southern Thailand between the first and 15th century based largely on Briggs (1951) and Groslier and Artaud (1957), and the distribution of wild cattle (inside heavy-hachured line) in northern Cambodia, based on the 1951-52 and 1963-64 field studies. Solid circles, cities; open circles, villages or towns; solid square, monuments or ruins; open square, inscriptions or smaller ruins; triangle, artificial waterholes. Question marks indicate that the presence of wild cattle is doubtful. Basic topographic data from Khong sheet, 1:1,000,000, U. S. Army Map Service 100056, 1944.

dikes, were able to subsist through the dry season and produce two or possibly three harvests a year. It appears possible, moreover, that they may have used a canal system to deposit fresh silt and ashes over their terraced paddies yearly, similar to the practice of the Hunzakuts of Pakistan and the Ifugao of Luzon.

It would be advantageous to know the details of rice cultivation among the ancient Khmers north of the established hydrophytic community. It could perhaps be considered dry paddy which according to Grist (1953), needs an assured rainfall for only a three or four month period. He states that "... under controlled irrigation ... water required is much less than that for wet paddy, and irrigation would be required for a shorter period."
Regrettably, the canals, dikes and basins of the Khmer, understandably less conspicuous than the royal palaces and temples, have been least investigated so that their true extent in northern Cambodia is scarcely known.

The Khmer civilization flourished from the 9th century until its disintegration following a Thai invasion in 1431. Evidence points to a deterioration of soil husbandry via failure to maintain the huge irrigation complex directed by the former supreme political power. Groslier and Arthaud thought that with neglect of the irrigation system periodic applications of alluvia (with ash from burned areas?) were prevented. The Khmers were apparently forced to rapidly emigrate from the population centers and resort to dry rice cultivation. Groslier and Arthaud write “... at the same time clearance by burning adopted from this time on, causes in this tropical climate laterization of the soil resulting in rapid and complete barrenness. Northern Cambodia, once an expanse of cultivated fields, became the dead savanna familiar to us today.” USAID-CFS scientists conclude “there is considerable indication that, in the days of the Khmer Empires, extensive areas of these lands were cultivated, depleted and abandoned.” Brigg's (1951) theory that the collapse was due to the burden of maintaining enormous monuments to greedy gods as well as to internal sedition by Hinayanism, and Brooks (1949) theory of an increasingly moist climate about 1050, seem less satisfying explanations than one involving a deterioration of man-land relationships. It would be most helpful to know whether or not the rice used by Khmer population centers in the northern plains was actually grown locally or grown more distantly on the alluvial plains and Mekong delta and distributed over the excellent road system these people were said to have. It would seem that the deterioration of either an irrigation system or an efficient transportation system could have forced the population towards widespread shifting cultivation.

Most rice cultivation today in the savanna forests is confined to small paddy fields in local depressions. Here yields are low (600 kg. per hectare) and repeated puddling of soils in these low places often leads to the formation of an impermeable hard-pan layer at a depth of from 15 to 25 cm. below which the soil is very dry.
Abandonment of these rice fields may result in the present day glades and strip savannas noted through the study areas.

Throughout the savanna forest the present day picture is one of the abandonment of many villages and the constant movement of others. This was dramatically brought to my attention in 1964 when I tried to find the village of Kakek some thirty miles west of our study area. I had visited it in 1952 and to my astonishment the entire village had moved five miles further west (Fig. 15). Roads change even oftener; no two maps appear to show similar roads in the northern territory.

Whether or not rice farming in the low areas of the present savanna forest led to eventual soil exhaustion above the inevitable hard-pan layer is questionable. Dry rice agriculture, on the other hand, can be as abusive as any other form of shifting cultivation. Unlike wet paddy, the cultivation of dry paddy rice, except in experienced hands, requires a constant shifting of the area of cultivation. According to Grist (1953): “... this simplest form of cultivation entails the wanton destruction of forest, all or practically all the trees being felled and burnt... the abandoned clearings frequently fail to revert to forest, but become poor grassland, often after serious soil erosion by reason of the torrential rains experienced in the tropics.”

In Burma dry paddy is grown in formerly forested areas having 50 inches or more of annual rain. Normally, in cultivating dry paddy, the soil is ploughed to three inches and the plants are at least 12 inches high before the soil becomes waterlogged. The system apparently demands labor and care exceeding wetland culture and constant protection against wildlife.

While most land in northeastern Malaya can be used for typical dry paddy, a very small proportion of land can be used for either dry paddy or irrigated dry paddy depending on the wishes of the cultivator, according to Grist. A more or less permanent village such as Chhep near our 1963-1964 study area is probably located near an area of similar favorable terrain possessing suitable soil such as the grey hydromorphic type. The bulk of northern Cambodia would necessarily have been typical dry paddy and, owing to the nature of the soil, a shifting type. It is difficult to see how a large
population, such as existed at the close of Angkor times, could have been long maintained by shifting dry paddy tillage, and it seems reasonably certain that large areas of the northern plains would have been modified by this practice.

If dry rice agriculture was practiced throughout northern Cambodia, as suggested by Groslier and Arthaud, it must have been done on a large scale somewhere between 600 and 1200 years ago and the formation of the larger areas of savanna forest may have begun at that time. The "shifting villages" of the dry paddy producers maintained oxen for tillage but largely for transport. To improve their pasturage, villagers doubtless used fire, which has since been encroaching on and destroying the last and wettest remaining vestiges of the sub-humid forest.

The present day distribution of the Cambodian population is centered in certain major and minor towns as shown in figure 16. Major towns in eastern Thailand lie along the Mun River or the railroad which parallels it. The population in the Mun valley and the humid forests (if still present) clothing the northern slope of the Dangreks...
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may act as effective barriers against the movement of wild cattle from their range within northern Cambodia, extreme southwestern Laos, and in Viet Nam along the headwaters of the Srepok River.

MAN AND FIRE

Small villages that persist in northern Cambodia (not shown in Fig. 16) seem to be the last hardy vestige of a former mode of life. They still retain oxen, largely for milk, transport and limited tillage. During the six long months of the dry season the villagers revert to a hunting and gathering pattern of life, at least in the areas where we have conducted our studies. Ox-carts carry them in ever widening circles of forage through the countryside surrounding their village until the last vestige of animal and plant food can be wrested from the environment. The details of this foraging may help us understand the role which fire plays.

The savanna or open forest is considered a sub-climax or plagio-climax. It has been subject to a “nationwide habit of indiscriminate burning” according to USAID officials. If it is a national pyromania, it certainly is not confined to Cambodia as so ably documented in other lands by numerous authors including Sauer (1944), Eiseley (1946), Richards (1952), Bartlett (1956), Steward (1956), Oakley (1961), Phillips (1965) and Komarek (1965).

There are abundant motives for burning in Cambodia and most are practical. Burning facilitates the search for saleable items (to the oriental apothecary trade) such as castoff deer antlers; it aids also in the search for resins exuded by certain dipterocarps. Fire aids in finding the stump holes which conceal edible turtles and allows the forager to see the large monitor lizard (Varanus salvator) (Fig. 17), sunning or stalking about. Cambodians fire the savanna to provide better grazing for their frequent ox-cart foraging trips and since ox-carts move at random over the area, burning is essential to avoid the pitted and rough terrain invisible under grass cover (Fig. 18). Movement by ox-cart is, coincidentally, not extensive until about the time the new green grass becomes available. Since a “road” may be scarcely more than two traces cut by the narrow wheels of ox-carts, it is difficult to follow until the high grass is burned. Oddly, bicycles are used in these ruts—we met several
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Fig. 16. Distribution of present day population centers in Cambodia and southern Thailand and the distribution of wild cattle in northern Cambodia. Towns in southern Thailand based on map of the National Geographic Society scale 1:4,707,648 January, 1965. Solid circles, major towns; open circles, minor towns. Wild cattle range is largely within the heavily hachured line; question marks indicate an unknown boundary.

groups of men en route from Kam Keut to Damphlet along a barely discernable trace which took days of hard work to prepare for the passage of four-wheel-drive vehicles (Fig. 19).

How much burning is done to remove ambush cover for tiger and leopard is unknown. Natives in the area expressed no fear of the large cats, in spite of the fact that a village in eastern Cambodia was abandoned after four people had been killed by tigers.

No evidence of hunting by use of the fire drive was found by our mission. Burning is done, however, to facilitate hunting. Basically, only the visual sense of man equals the exteroceptor senses of the wild herbivore. In tall dry grass cover, the human hunter is at a disadvantage; animals in repose cannot be seen until one is too close, often only their horns protrude above the grasstops even when standing. Burning benefits the human stalker who must by quick
FIG. 17. A Cambodian returns to camp after a successful afternoon’s foraging, having captured a large monitor lizard (*Varanus salvator*) and some terrestrial terrapins. The arid savanna forest has been newly burned.

FIG. 18. An elephant-borne scouting party approaches a herd of banteng feeding on newly sprouted grass in savanna forest near Trapeang Roun, Kampong Thom province, northern Cambodia. Fire has burnt off the heavy grass cover revealing the rough and pitted terrain formed by a species of subterranean annelid worm.
FIG. 19. Workers clear a road through rough, worm-mound terrain in Veal Saik-Lact, near Phnom (hill) Barai in northern Cambodia. This burned glade in savanna forest is probably largely inundated in the wet season. Kouprey, banteng and Eld's deer were observed here.

FIG. 20. Savanna forest with an understory of cane grass (*Arundinaria ciliata*) and numerous termite mounds. Fire has swept through this forest leaving some unburned clumps of grass.
glances, place his feet quietly and properly in order that he may stop instantly in perfect balance. Obviously, heavy grass not only is noisy but impedes the placing of the feet. A direct, rapid, straight line stalk is the only practical way we found of approaching wild herbivores. The stalker must never bend over but must remain entirely upright and with arms held tightly to the sides. The head of each member of the grazing herd must be watched; if one head is raised the stalker stops and becomes in effect a tree stump (a burnt stump if one is wearing dark clothing). In this way grazing herbivores often can successfully be approached even across open fields. Crawling is too slow and any lateral movement is quickly detected. Our field parties were not successful in approaching wild cattle until the annual fires had removed the tall grasses. Unfortunately, at that time, due to increasing heat the animals appear to feed largely at night, lying up in thicker forest during the day. They may even enter semi-humid forest, Wharton (1957).

Of equal importance in hunting wild cattle is the ability to track the herd. Tracking through unburned old grass cover on hard ground is especially difficult (Fig. 20). Burning facilitates tracking, both on the new ash and following the first rains. Thus, fire aids the Cambodian hunter whether he walks until he sees animals feeding in the distance and then stalks them, or whether he tracks up the herd and then makes a final stalk. Even though flushed by the sight or smell of on-foot hunters we found that wild cattle would seldom run over one kilometer before they resumed feeding.

As to whether scrambling wild cattle dislodge boulders of ironstone which, striking other stones, start fires as Hough (1926) has suggested in Burma, we have no evidence. While some fires in Cambodia may result from lightning, it appears to me that most of the savanna forest is burnt off before the first thunderstorms ever darken the skies.

Some fires are accidental, as in smoking or singeing bees which, conveniently, build a big comb hanging in a small tree or bush (Fig. 21), and some campfires are left burning. Most fires appear deliberate, however. In 1964 our hunter-farmer guides from the village of Chhep independently and systematically began to fire the grass wherever our field parties travelled. They seemed to know,
moreover, precisely when each area and each kind of grass would burn. Their progress could be followed for miles by a chain of smoke clouds. Also, it was amusing to watch them develop skill in setting fires from a moving vehicle.

After foraging parties work the areas close to their villages they eventually reach peripheral areas. One of these was chosen as our 1964 study area. In early January parties of Laotian hunters had crossed the Tonle Repou and were hunting in this region and a military hunting party had travelled 80 kilometers to reach it. Between February 1 and the end of April as many as ten ox-carts loaded with a number of families were encountered camped at permanent water-holes to trap fish, and hunt for reptiles and honey. These parties must contribute to the firing of the remaining patches of unburnt grassland (Fig. 22). They build racks to dry fish and prepare “jerky” from wild beef and venison. Such foraging expedi-
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Fig. 22. Fire in a glade in savanna forest south of Phnom Patorr, Kampong Thom province, northern Cambodia. Cambodians set fires as soon as the grasses burn readily, usually in January or February.

...tions are timed to coincide with dropping water levels in waterholes (Fig. 23) and stream beds. There is no flowing water in this part of Cambodia in the dry season except in certain large streams such as the Stung Sen.

The foraging by villagers is extensive and includes capturing or killing vertebrates from fish to elephants. Every permanent water hole (those which never completely dry up and thus have fish in them) is repeatedly visited. Most reptiles are immobilized and carried back alive draped over poles (Fig. 17). Some formidable creatures are captured. Crocodiles (*Crocodylus siamensis*) are captured in drying up stream beds within heavy gallery forest such as along the Tonle Repou, the intermittent stream that forms the boundary between Laos and Cambodia west of the Mekong. Crocodile skins are sold as well as skins of the regal python (*Python reticulatus*) which is found in the sub-humid and humid forest. Pangolin (*Manis pentadactyla*) are much valued for their scales which are sold to the Chinese apothecary trade, and the young of leopards, tigers and
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Fig. 23. A waterhole in savanna forest, surrounded by lush green grass. These terrain features are of major importance to both man and wild cattle in northern Cambodia. Permanent waterholes have water the entire year. The water appears pure and is readily drunk by foraging villagers as well as by all types of animal life.

gibbons are captured for resale. Deer (Fig. 24) and wild cattle are frequently taken with either ancient flintlocks or, in some cases, modern military weapons. Often an ambush is held at a waterhole or salt lick (Fig. 25). Even elephants are at times shot.

During the incendiary season, fire endangers any established camp. On February 10 we were forced to fight a severe fire which threatened our camp at Trapeang Roun even though the camp was situated in the remnants of sub-humid forest. We were forced later to burn a protective perimeter to prevent the loss of the camp.

Most Cambodians carry a cigarette lighter—this is true even of many Mnong hill people. During our visit to Mondol Kiri an entire village would cluster about the vehicle and beg for gasoline for their lighters.

In December, 1964 on a flight from Phnom Penh to Lomphat in Ratana Kiri Province, several fires were noted in progress. From
then until mid April the smoke and smell of fire is constant in the northern plains.

The combustible material is of three basic types. A waist high bamboo grass (*Arundinaria ciliata*) forms a uniform dense ground cover on plinthite podzols and on higher terrain (Fig. 20). On compact hydromorphic clays subject to flooding a variety of tall grasses of the genera *Themeda*, *Chloris* and *Arundinella* form a characteristic growth (Fig. 22). In sandy arid savanna forest the sedges *Fimbristylos*, *Cyperus* and *Cladium* appear to dominate (Fig. 10).

The bamboo grass, preek, seems to burn first (in places) (Fig. 20), followed by the more open savanna forest. By mid-February the arid savanna forest begins to burn patch by patch (Fig. 10). It appeared that either the sandy soils of this beautiful parklike terrain held moisture longer, or their scant grass-sedge cover died last. In 1951 it was assumed that this area never burned and we were astonished to see large parts of it on fire in 1964.
By April 10 the new bamboo grass is 14 cm. high; by mid-April coppice growth of such dominant trees as Shorea obtusa are sprouting lushly. A few light "mango rains" occur in April but hardly enough to account for this rapid burst of vegetation coupled with the blooming of characteristic flowers such as Plubaat (Dillenia hookeri). The fire season terminates by mid-April—we noted some stumps still burning as late as April 12. Some of the resinous varieties may burn for several days. Ogawa et al. (1961) picture a hole in the trunk of a Thai dipterocarp which had been set on fire to stimulate production of oil. In 1952 I saw a number of such holes in dipterocarps in Cambodia.
of bamboo. The apparent absence of small rodents is evidence supporting the comparatively recent origin of the savanna forests of northern Cambodia.

Feeding movements of deer and wild cattle are markedly controlled by the pattern of fire burns. Total movement is in addition influenced by other factors such as the drying up of waterholes or the increasing diurnal heat. It now appears that wild cattle use the sandy arid savanna forest for winter pasture as well as certain high ground near hills where flooding is infrequent. They break up into small groups at the very commencement of the dry season, apparently resorting to the tall grass to drop their calves which are, however, born early enough not to be endangered by fire. Both the dense and open savanna forests burn in patches. Tall grasses near waterholes burn early and by mid-March are being regularly visited by wild cattle for the oasis of tender green grass surrounding the dropping water level (Fig. 23). The earliest record of wild cattle feeding in a burn was that involving a herd of banteng which paid a nocturnal visit to a burned portion of open parkland 400 meters east of our camp on the O Kapok on January 25. This burn must have been about three weeks old. Elephants and water buffalo leave the savanna forests for the larger gallery forests in the latter half of January and do not return until the first rains of April. Unfortunately for observation, wild cattle become nocturnal visitors in the more open savanna forests of northern Cambodia during the major part of the dry season. Only at the beginning and the end of the rainy season can they be regularly seen in the more open terrain; at this time they form large herds.

DISCUSSION AND SUMMARY

It is suggested that 2000 years ago the destruction of Cambodia’s sub-humid climax forests began to change the face of the northern plains. Between 600 and 1200 years ago, dating largely from the 9th century, this area developed a savanna forest complex of vegetation, a biota drastically altered by man’s efforts at both dry, shifting agriculture on high, unflooded ground (cheomka system) and his later shifting, dry paddy agriculture on lower ground and flooded
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terrain within this ecologically diverse habitat. Only on the Kontum Plateau has true cheomka agriculture persisted to the present day by virtue of the rich volcanic soils which the remainder of the northern plains does not possess. Even these rich soils can be made grassland and abandoned, as the Chhlong Plateau demonstrates.

That much of this savanna forest is of very recent origin is supported by the absence of a specific burrowing fauna in general, as well as the absence of certain small mammals in particular.

From the earliest records the Khmers possessed both domestic cattle and water buffalo and it is known that these animals are the only means of transport for foraging and commerce throughout the northern plains. The burning of the environment to provide better pasture for domestic stock has thus been of selective advantage for those few villagers who remained in this difficult terrain. The present day movement and abandonment of villages seems to attest the precariousness of shifting agriculture, paddy or otherwise, which, lacking technical or administrative direction, provides us with more understanding of the deterioration of the great Khmer civilization of Angkor times. In this case, the present ecology of the northern Cambodian may be a key to his past.

If shifting dry paddy agriculture has been precarious on some northern Cambodian soils it has apparently been disastrous or impossible on certain others such as the plinthite podzols. Those villages such as Chhep, favorably located near larger areas of grey hydromorphic soils, may persist for many years. Most villages, apparently, must move periodically or disappear.

It would appear that fire in the northern plains of Cambodia has aided in the degradation of some soils and most of the vegetation cover over the area originally clothed by sub-humid climax forests. Fire seems, however, to be an essential factor in maintaining suitable large areas of savanna forest exploitable by both wild herbivores and by a very small population of hardy Cambodians.

It remains to determine what parts of northern Cambodia, by reason of edaphic control or otherwise, might have been savanna terrain (with lightning-caused fire) prior to the advent of man. Such information will be necessary to determine the extent of those areas which might be termed natural wild cattle range offering a combina-
tion of environmental advantages such as good grazing, permanent waterholes and salt licks.

The location of present day Cambodian population centers and their way of life in the hydrophytic community is a return to the days of the Mekong Delta riziculture of their ancestors, along with the rediscovery that a stable and prosperous civilization can be maintained only on true wet land rice and fish. Especially is this so if the strong central control of a god-king cannot make mandatory renewing of the soil by vast and costly irrigation systems.

We are led to understand that the protein need of the northern Cambodian is such that it compels him to revert to an earlier pattern of hunting and gathering for his dry season life.

Noting the intimacy of his association with the environment and its wild herbivores, and noting his maintenance of this environment by his fire habits, it appears that, over much of northern Cambodia, man and wild cattle have gone a step beyond commensalism to perhaps achieve a state of protocooperation (facultative mutualism of some authors) in which each benefits the other and neither is unduly harmed. Our next task is to determine just how long and profound this relationship has been, and how much and how long fire has really played a role in its development.

In the pursuit of this, the zoologist is sobered and stimulated by the fact that the great carrying capacity of the fire-maintained grasslands is largely man-oriented, leading us to examine more closely the ecology and paleoecology of wild cattle since their pliocene ancestors were entombed in the Siwalik foothills of the great Himalayan range.

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