ANTROPOLÓGICA
52, 1979: 39-76

- DESMONTE, YANOMAMÖ
- YANOMAMÖS, DESMONTE
- TALA, HACHA DE PIEDR
- HACHA DE PIEDRA, YANO

FOREST CLEARANCE AMONG THE YANOMAMÖ, OBSERVATIONS AND IMPLICATIONS

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Over the last quarter-century, slash-and-burn agriculture has received a great deal of attention from anthropologists. Indeed, it is now one of the best described of all modes of subsistence. Yet, in the many descriptions of it that have appeared, one phase is almost invariably slighted: the clearing of the forest. Oftentimes, little more is said about it than that the undergrowth is cleared and the trees are felled.

Aware of this gap in the literature on swidden cultivation, I made a special effort to observe and record forest clearance during a brief stay with the Yanomamö Indians in 1975 [1]. In April of that year I lived, along with my field partner Kenneth R. Good, in the Yanomamö village of Hasuböwateri, located near the south bank of the Orinoco River, midway between the rapids of Guaharibo and Peñascal.

The month I stayed with the Yanomamö did not coincide with the forest clearing season, so I asked them to clear a tract of primary forest for me in order to observe them at this work. The average size of a Yanomamö garden plot is about 1.7 acres (Smole 1976: 137), but the tract I had them clear was only 1/6 of an acre [2]. I would like to present

1. This stay occurred while I was a member of an ethnological expedition to the Yanomamö led by Napoleon A. Chagnon and including Eric Fredlund, Kenneth R. Good, and Raymond Hames, with William T. Sanders and I serving as consultants. The expedition was supported by the National Institute of Mental Health under grant SSR 5 RO1 MH26008.

2. In the village of Karohi, located in an area environmentally similar to that of Hasuböwateri, Jacques Lizot (1971: 156) found that the aver-ge size of a garden plot for all cultivators was 3,057 square meters, or .75 acre. However, important men with greater responsibilities for providing food and drink on special occasions, had larger plots. The average size of their gardens was 5,880 square meters, or 1.45 acre.

The reason for choosing 1/6 of an acre was that I had previously made measurements of rain forest trees in a plot this size in Luquillo National Forest in Puerto Rico, and wanted to be able to compare these data with those gathered in a tract of forest of the same size in southern Venezuela.

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the results of this study here, and to discuss some of its implications.

CLEARING THE UNDERGROWTH

As is true of all swidden cultivators, the first thing the Yanomamö do once they have chosen an area of forest for the site of a garden is to clear the undergrowth. This is done first so that a man will not be impeded by the low vegetation while he is wielding his axe in felling the trees. I am not prepared to describe how the Yanomamö cleared the undergrowth aboriginally, but nowadays it is done with a machete[3].

In clearing the low vegetation a Yanomamö may start anywhere within the area he expects to fell. He squats on his haunches, machete in hand, and begins to cut (see Fig. 1).

Fig. 1 Hööhawa, a young Yanomamö; clearing the undergrowth in the experimental plot with a machete. All low vegetation is cut flush with the ground.

3. In clearing the undergrowth before felling the trees, the Kuikuru of central Brazil formerly used piranha mandibles, with the teeth in place, to saw through saplings, although sometimes a man would simply break the stem of a sapling and then bend it over. The Amahuaca of eastern Peru employed heavy palm wood sword-clubs with which they toppled the smaller vegetation, especially the bamboo which grows profusely in their forests.

Most of the time he remains in this position, although occasionally he may rest one knee on the ground. To move around on the forest floor, he stays on his haunches and "duck-waddles" from place to place.

The Yanomamö cut the smaller vegetation flush with the ground[4]. Sometimes a man will chop just below the ground to cut a plant at root level. Some plants are occasionally pulled out by the roots, but this is rare. Almost everything is cut by machete. If a seedling is very flexible, it may be held out at an angle with the left hand and cut with the right.

As a man finishes cutting a batch of vegetation, he usually pushes it behind him, but sometimes throws it to the side. Occasionally it is placed in small piles, apparently so it will burn more readily. Any vegetation that is cut near the edge of the plot is generally thrown into the plot instead of outside of it. This also appears to be done to enhance the burn. Some men use their hands a good deal to scrape away dead leaves and other debris from around the base of a sapling before cutting it.

Men carefully clear the area around a large tree, and if any vines are growing along the trunk or near it, they are usually hacked away. An old stump, if partly decayed and not too thick, may be hacked out with the machete. Care is taken, though, to work around nests of stinging ants, which are not uncommon on the forest floor.

I could discern no fixed pattern in the way a man moves through a plot while he is clearing the low vegetation. Sometimes he may clear a circular area all around him, but other times he will move forward along a straight line.

Every growing plant up to about 2 inches in diameter is usually cut with the machete, anything thicker generally being left to cut later with an axe. Vines are the only exception. Even if they are as much as 3½ inches in diameter, they are cut with a machete, since, being relatively soft and succulent, they offer little resistance to the blade. Moreover, since a dangling vine does not make a very solid target, it is easier to cut it with a machete than with an axe. As a rule, a vine is first cut where it enters the ground and then the dangling length is cut higher up, around eye level. If a vine hangs down in a loop, it is usually chopped in mid-air, but may be held against the trunk of a tree for easier cutting.

The Yanomamö work diligently and rapidly in clearing the un-

4. In this respect, they offered a marked contrast to the Kuikuru, who instead of squatting down to cut the undergrowth, merely bend over at the waist and cut saplings diagonally through the stem a foot or two above the ground.

dergrowth. Three of the men I timed all chopped at the same steady rate of one stroke every two seconds. Moreover, they worked for long periods without interruption. One young man, Hööhawa, cut undergrowth for 2 hours and 12 minutes without stopping except for a couple of times when he spent a minute or so sharpening his machete. And he was chopping just as vigorously when he finished as when he started[5].

The Yanomamö are careful and thorough in the way they clear the undergrowth when making a new garden. If they are newcomers to agriculture, as is sometimes alleged (e. g., Zerries 1964: 53), they have made giant strides.

TIME SPENT IN CLEARING

One of the objectives of my study was to determine the time it took the Yanomamö to clear the low vegetation in preparing a new garden plot. I was able to do so rather precisely. Altogether, 4 men spent a total of 8.7 man-hours clearing the experimental plot. Since this plot was 1/6 of an acre in size, and Yanomamö gardens cover about 1.7 acres, this means it would take some 88.9 hours to cut the low vegetation in clearing a typical one.

What effect has the acquisition of machetes had on the time it takes the Yanomamö to complete this phase of swidden cultivation? Certainly, machetes have lightened the work of clearing the undergrowth, but how much they have actually saved is very hard to judge. It seems likely, for instance, that aboriginally the Yanomamö did not clear the low vegetation as thoroughly as they do now. They may have been content merely to clear immediately around the trees they intended to fell and leave it to the subsequent burning of the plot to consume the rest of the shrubs and saplings. In that case, the introduction of the machete may not have saved the Yanomamö so much time after all. But in the absence of detailed information about aboriginal clearing methods, this is little more than idle speculation.

THE EXPERIMENTAL PLOT

Once the Yanomamö have cleared the undergrowth, the next step is to fell the trees. This is a much more arduous task. The Yanomamö live in a luxuriant rain forest where the trees are large and hard. Before

5. What made this all the more remarkable was that earlier that morning Hööhawa had returned from a neighboring village where he had suffered a deep gash in his scalp during a club fight.

proceeding to describe tree felling, though, I must say something about the composition of the forest in the experimental plot.

The plot was located on level ground about 300 yards from the Orinoco, well above its narrow flood plain. In delimiting the plot, I cordoned off an area of forest that seemed typical of the region. However, I purposely included within it a very large tree with extensive plank buttress roots since I wanted to see how the Yanomamö felled such a tree. The 1/6-acre plot contained 124 trees 1 inch or more in diameter. Exactly half these trees, 62, were 2 inches or more in diameter, and 13 trees of the 62 were 10 inches or more in diameter[6]. Projecting these figures, we can say that a plot of average size (1.7 acres) would have some 1,265 trees an inch or more in diameter, 632 trees 2 inches or more in diameter, and 133 trees 10 inches or more in diameter.

I might also note the great diversity of trees in the experimental plot. The 124 trees growing within it represented no fewer than 44 different species[7]. Nor was this degree of variety unusual. In another 1/6-acre plot whose trees were identified for me by the Yanomamö of Tayariteri, further down the Orinoco, there were 56 different species of trees. These counts reflect a fact well known to botanists, namely, that tropical rain forests are much richer in tree species than temperate forests. To give a concrete example of this, the two Yanomamö plots I studied, which together comprised a mere third of an acre, contained no fewer than 87 different species. By contrast, the entire state of Michigan —more than 100 million times larger than the two Yanomamö plots— has only 89 native species of trees (Otis 1926).

Another fact of note about trees in the forest around Hasuböwateri is that they are very hard. In Table 1,

6. Following the usual practice in forestry, I measured the diameter of the trees at breast height.
7. The Yanomamö proved expert at tree identification. Not once did I point to a tree which they were unable to identify. Moreover, that native names correspond very closely to botanical species is the opinion of tropical foresters who have had experience with native informants in Amazonia (e.g., Richards 1952: 232; Guppy 1958: 7, 49, 65, 83, 284n.).

TABLE 1

HARDNESS OF TREES GROWING IN OR NEAR THE EXPERIMENTAL PLOT AT HASUBÖWATERI, AS MEASURED BY SPECIFIC GRAVITY

	Yanomamö Name	Probable Botanical Name	Number of Specimens Tested	Average Specific Gravity
1.	tǫǫmoro		2	1.029
2.	sibarakohi	*Swartzia arborescens*	1	.989
3.	masirikohi		1	.925
4.	mǫtuakehi	*Dalbergia nigra*	2	.914
5.	roakehi		4	.868
6.	paitanari		1	.864
7.	habromikehi	*Duguetia* sp.	2	.829
8.	yotoknato	*Malpighiaceae*	1	.826
9.	yorokosihi		1	.787
10.	hokotomari	*Eschweilera subglandulosa*	1	.779
11.	ąri'ahi		1	.773
12.	mahei		1	.580
13.	warabakohi	*Hemicrepidospermum rhoifolum*	1	.563
14.	hąhǫnatahi	*Cordia* sp.	1	.560
15.	shitibori	*Jacaranda copaia*	1	.442
16.	shįkįknato (sëki ka natho in Lizot's transcription)		1	.381

Botanical identifications are taken from Lizot (1975) except for *motuakehi*, which I tentatively identified as rosewood, *Dalbergia nigra*, on the basis of the characteristic odor of its oil. Specific gravity of each wood was determined in the laboratory from chips cut from the trees at the time of felling and brought back from the field. The chips were air dried and the procedure used in ascertaining their specific gravity is that described by Record (1914: 136-137).

I have listed those 16 species of trees felled in the experimental plot whose hardness I was later able to establish [8]. No less than 4 of the trees growing in the plot were harder than the hardest of all North American trees, osage orange (specific gravity .85 to .90). Moreover, 11 of the 16 trees were harder than all North American trees except for osage orange and perhaps hickory and locust. It is clear, then, that in felling a tract of forest a Yanomamö faces no easy task.

8. As I will explain later, the index of hardness I used is specific gravity, which correlates closely with hardness and is relatively easy to ascertain.

FELLING THE TREES

While around the turn of the century they were still using stone axes [9], the Yanomamö today use steel axes in felling the forest. The axe heads are, of course, of Western manufacture and are traded in from the outside or obtained as gifts. The wooden handles, however, are made by the Yanomamö themselves. They are long, straight, and tapered, the distal end being thicker than the proximal end. To haft an axe, a Yanomamö simply inserts the smaller end of the handle into the hole in the axe head and pushes it through as far as it will go. When it is firmly in place, a couple of inches or so of the handle protrude beyond the top of the axe. This method of hafting is simple yet effective. The Yanomamö never have to worry about the axe head coming loose and flying off the handle [10].

In wielding an axe, a Yanomamö generally places his right hand above his left, as European loggers do. However, one man I observed chopped cross-handed. Being short —men stand barely 5 feet— the Yanomamö find it advantageous to choke up on the handle, holding it about a third of the way from the end.

When the time came to begin felling the trees in the plot, the Yanomamö who was to initiate the work asked me where I wanted him to start. I replied that the choice was his, that I wanted him to fell the trees just as if he were clearing a new garden for himself. I am confident, therefore, that the plot was cleared in the customary Yanomamö way.

To my surprise, the first thing the man did was to fell a large tree that stood about 20 feet outside the plot. He cut it so that it fell away from the plot, thus pushing back the edge of the forest a bit in that sector, thereby increasing the amount of sunlight the plot would receive. The felling of trees in a direction away from the plot recurred several times during the experiment. Even trees that lay within the plot but near the edge of it were generally felled so that their crowns and most of their trunks would land outside the plot. In falling, these trees some-

9. A widespread but erroneous view, held even by anthropologists, is that before the introduction of metal axes, Neolithic man, with only his stone axe, was incapable of clearing high forest to make his garden plots. J. D. Freeman (1955: 42), for example, writes: "... the Iban system of agriculture, involving as it does, the felling of large areas of virgin jungle, is dependent on the use of iron tools. Such extensive methods could not be followed by a neolithic people". And Frank Livingstone (1958: 550), writing about West Africa, has argued that "it was not until the introduction of iron working... that the Negro agriculturalists could exploit the tropical rain forest". (See also Clark 1945). However, the facts of aboriginal Amazonian ethnology are enough to dispel such a view. (See Carneiro 1974.)

10. The Kuikuru haft their axes in the same way.

times brought down other trees that lay outside the boundaries of the plot, thus opening it up to sunlight even more.

Another advantage of cutting the trees near the edge of the plot to fall outside of it is that less of the plot will be covered by tree trunks and thus more of the ground will be available for planting [11].

When a Yanomamö starts cutting a tree, he begins on the side facing the direction he would like it to fall. Up to a point, a man can make a tree fall in any direction he wants. However, if the tree is leaning heavily in one direction, it may not be possible to have it fall in any other. If several men are clearing the plot together, they generally discuss which way a tree should be felled, especially if it is a large one.

A Yanomamö fells a tree much as a European logger does. First he notches it on one side and then cuts into it on the opposite side. There are differences, though. A European logger makes a relatively shallow notch, usually less than a quarter of the diameter of the trunk, whereas a Yanomamö cuts a much deeper notch, almost half way through the trunk [12]. Moreover, when he shifts to the opposite side of the tree, he starts cutting at the same level as the notch instead of 3 or 4 inches above it, as European loggers do.

When a Yanomamö approaches a tree he is going to fell, he may tap the edge of his axe lightly against the trunk once or twice to mark the spot to receive the first blow. This spot is usually 32 to 35 inches above the ground. When the chopping begins, several strokes are delivered diagonally against the trunk at an angle of about 20° or 30° above the horizontal. These are followed by strokes delivered at right angles to the trunk. Series of diagonal and horizontal strokes are alternated during the felling.

As the cutting proceeds, chips fly in various directions, perhaps as much as 20 feet if the wood is very hard. Occasionally a man reaches into the cleft and tears loose some chips from it in order to tidy it up.

The Yanomamö fell a tree very economically. They use a minimum of strokes, making every stroke count. The degree of control a Yanomamö has in cutting a tree is very impressive. He can lay his axe exactly where he wants to almost every time. One can see the effects of this control by examining the cleft. It has the shape of a 'V' on its side, and the "floor" of this 'V' is quite flat and clean. But while flat, the cutting floor is not

11. With the passage of time, though, even the most trunk-bestrewn garden plot gets tidied up, as dead logs are cut up and carried away for firewood, and stumps decay and are burned out or hacked out. A large plantain garden at Hasuböwateri that was at least 6 years old was completely clear of fallen trees except for one huge stump.

12. To judge from an illustration in Ruddle (1974: 71), the Yukpa of the Sierra de Perijá also make a deep initial notch on the fell side of a tree in cutting it down.

entirely level. It slants down slightly from the center of the tree and is also inclined a little toward the cutter.

Three months after leaving the Yanomamö I had occasion to observe the Kuikuru felling trees and found their cutting to be less controlled and precise than the Yanomamö's.

When a Yanomamö has deepened his initial cut a few inches, he moves around the trunk a bit and begins extending the cut laterally. Then he changes his position again and extends the other end of the cut. Eventually, he may cut 180° around the circumference of the tree. After doing so on the "notch" side of the tree he repeats the same procedure on the other side. If a man has cut deeply into both sides of the tree and it still has not fallen, he may then switch back and forth between the two sides as he continues to cut.

There seems to be a rough correlation between the hardness of a tree and the percentage of its cross-section that must be cut in order to fell it. Thus, only about 40 percent of a soft *shitibori* (specific gravity .442) was cut through before it fell, while about 90 percent of a hard *roakehi* (specific gravity .868) had to be cut before it would go down. However, the correlation is not hard and fast. The percentage of the cross-section of a tree that needs to be cut is affected by various factors. If it is hollow, or if it leans perceptibly, it will take less cutting, while if it is supported by a neighboring tree more of it will have to be cut through.

The Yanomamö do not chop steadily, but in bursts. During an average burst, a man delivers 21 strokes in 31 seconds, or a stroke every 1.5 seconds [13]. This is followed by a period of rest of about 30 seconds or less. The briefest chopping burst I recorded was 10 strokes in 15 seconds, and the longest was 59 strokes in 84 seconds.

A Yanomamö works hard in felling trees. Occasionally he indicates this by emitting a low whistle or by making some exclamation, such as "*huooo,*" or "*brahahahaha*". Sometimes, referring to the tree he was cutting, a man would say "*hihuwa*" (hard) or even "*waiteri*" (fierce) [14]. And, as we have noted, the wood of many trees in the plot was indeed hard. While cutting a *masirikohi* (specific gravity .925), a man actually bent the corner of his axe. Moreover, axes soon begin to lose their edge when directed against such hard wood, and if a steel file is available, a Yanomamö will pause for a few minutes to resharpen it. Prolonged

13. Townsend (1969: 203) reports that in using the steel axe the Heve of New Guinea deliver a stroke every 2.54 seconds, but he does not indicate the frequency or duration of rest periods.
14. The word *waiteri* is more commonly used to refer to a person, and represents what a Yanomamö man strives to be: hard, tough, mean (Chagnon 1968: 124, 127; 1974: 156).

chopping makes a man's hands sore, but he merely spits on them, rubs them together, and resumes cutting.

The Yanomamö prefer to cut the large trees first so that in falling they will knock over some of the smaller trees, obviating the need to cut them down by hand. In deciding in which direction to fell a tree, the Yanomamö take account of what other trees it might bring down with it. However, they do not notch any of the smaller trees lying in the path of a large one to facilitate their fall. Consequently, smaller trees sometimes snap off high up the trunk, or merely have part of their crowns sheared off, when hit by a large one.

While a Yanomamö usually has a pretty good idea of the direction in which a tree will fall, sometimes he is fooled. For example, the man cutting an *ąri'ahi* tree 24.8 inches in diameter thought first it would fall in a direction of 175°. Later he decided it would fall heading 30° instead. But it finally fell heading 290°. On another occasion, a *masirikohi* 9.1 inches in diameter, which was expected to fall in a direction of 240°, fell heading 85° instead.

Part of the uncertainty of how a tree will fall is because its branches are sometimes intertwined with those of adjacent trees which may at first impede its fall, and then affect the direction of the fall. This is especially true when the crown of a tree is linked to those of others by vines [15].

When a large tree is felled, it is hard to predict which other trees it will bring down with it, and in which directions they will fall. Moreover, a falling tree may shear off large branches from adjacent trees, which also fall, but often there is a delay of as much as a minute before they finally reach the ground.

Because of all of these uncertainties, felling a tree, especially a large one, involves an element of danger. And the Yanomamö treat a falling tree with due respect. They try to anticipate when a tree will fall by listening for cracks, and when they hear them they move back a safe distance. Occasionally, when a tree lets go sooner than expected, a man may have to make a quick dash to safety.

From long experience the Yanomamö know, even without a warning crack, when a tree is about to fall. Or at least they know when it *should* fall. Not infrequently, though, a tree will not go down when expected. Enough of its trunk may have been cut through for it to fall, but it refuses to do so. The Yanomamö then conclude that it is being

15. The secondary forests that grow up in Amahuaca territory abound in thorny bamboo, which also acts to bind tree crowns together. Largely because of this linking of the crowns, I once saw a large tree that had been felled by hand, bring down some 30 smaller trees with it.

held back by a nearby tree and start looking up into the foliage to see which one it is. When they think they have identified it, one man climbs up that tree, or one adjacent to it, and lops off the supporting branch with his machete. Its support gone, the main tree usually falls.

Since tree climbing is a common adjunct to forest clearance, I will describe it here briefly. A man cuts a length of vine about 8 or 9 feet long and some ⅜ of an inch thick. He loops this length of vine twice, and the third time winds the remaining length around the other two loops. Where the two ends come together, he knots them with a square knot. The climbing ring is then ready for use.

Then, standing at the base of the tree he means to climb, the man places the climbing ring over the instep of each foot. (For easiest climbing, the tree should be 6 to 8 inches in diameter and be free of limbs along most of its trunk.) Then, straddling the tree, he spreads his knees and rotates the soles of his feet upward so that each foot can press against the trunk from opposite sides. The climbing ring permits the climber to spread his feet as far as he needs to, but prevents them from separating any further.

The climber then embraces the tree with both arms, one hand being placed just above the other on the opposite side of the tree. To begin climbing, the man slides both hands up the trunk as high as he can conveniently reach, and embraces the trunk tightly. Next he raises his feet 25 or 30 inches by sliding them quickly up the trunk, and then clamps them against the sides of the tree to support his weight. Now he is ready to slide his hands up the tree again and begin another round of climbing. By this means, a man can climb a tree very rapidly. Indeed, to an observer, it looks more like bounding up the tree than climbing it.

When the climber reaches the appropriate height, he cuts off the branch that was interfering with the fall of the principal tree. If the offending branch is not on the tree he has climbed but on another, the man leans out from his perch and lops it off with his machete.

To climb down, a man clamps his feet against the tree more loosely and lets them slide down the sides of the trunk in a continuous motion. The hands, though, are not allowed to slide freely down the tree, or the climber would lose control of his descent. He simply lowers them alternately while continuing to embrace the tree. In this manner a man can descend from a height of 50 feet or more in a very few seconds.

Freed of interfering branches, a tree that has been cut sufficiently through is ready to fall. It often begins to fall slowly, almost imperceptibly, but quickly picks up momentum. The fall of a forest giant is an impressive thing to watch. First there is the cracking and splintering of the wood left uncut at the center of the tree; then there is the harsh rustle as its boughs brush past those of adjacent trees; and finally there is a thundering roar as its enormous trunk crashes to earth. After witnessing one such tree fall I wrote in my field notes, "A most dramatic, exciting, and strangely beautiful event".

FELLING TREES WITH PLANK BUTTRESSES

A good many of the large trees in the forest around Hasuböwateri have plank buttress roots. Extending out radially from the trunk, these buttresses present a special problem to the cutter. If the tree is not too large and its buttresses not very prominent, a Yanomamö will stand on the ground and cut through the buttresses to fell it. However, if the tree is unusually large or the buttresses are very pronounced, a scaffolding will be built on which a man will stand so he can chop above the buttresses, or at least where the buttresses are smaller. I observed these two types of felling and will describe each in turn.

The first involved a rosewood tree, *motuakehi,* with five plank buttress roots which flared in various directions. While the diameter of this tree, measured just above the buttresses, was 20.4 inches, at its maximum width, measured with the buttresses, it was about 60 inches. However, despite the buttresses, the Yanomamö who was to fell the tree decided not to build a scaffold but to cut it standing on the ground.

At the height at which the *motuakehi* was cut (some 35 inches above the ground) the trunk was largely buttressed (see Fig. 2). The Yanomamö who was to fell it began cutting buttresses A and B at their edge, and kept working at them until he had cut them entirely through, down to the central trunk. However, when he started cutting buttress C, his method changed. Instead of cutting this buttress edge-on, as he had the first two, he chopped at the side of it until he had thinned it substantially. Next he did the same to buttress D. Then he turned to the fifth and last buttress, E, which lay in the direction in which he wanted the tree to fall. This buttress he again cut edge-on. Every so often, though, he stopped cutting buttress E and returned to C and D, which he thinned some more until at last he had cut a "window" through each, leaving only a thin, narrow partition of wood in place near the edge of each of the two buttresses.

Again he returned to buttresses A, B, and E, and deepened the cuts he had made in them. Finally, when the *motuakehi* had been cut through to the extent shown in Fig. 2, it fell.

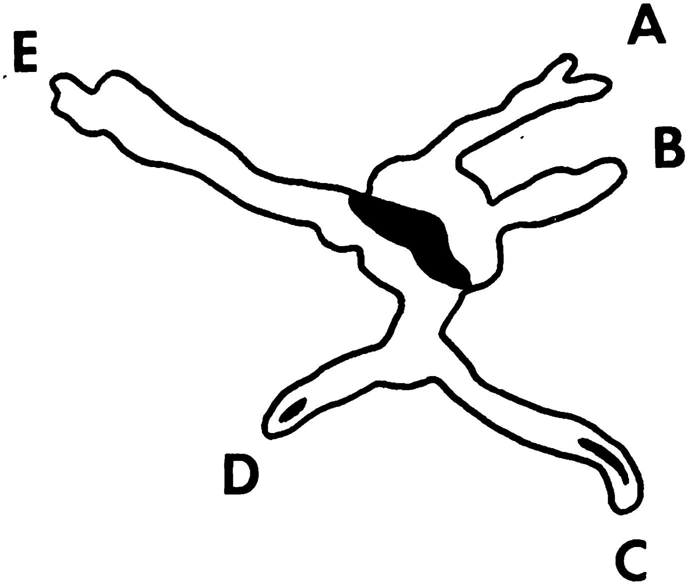

Fig. 2 Cross-section of the *motuakebi* tree along the plane on which it was cut, about 35 inches above the ground. The areas shown in black were not cut through, but broke away as the tree fell.

At first, the thinning of buttresses C and D had mystified me, but as the cutting progressed, I began to understand the reason for it. These two buttresses lay in a direction opposite that in which the Yanomamö wanted the tree to fall. But since the tree was perfectly erect, it could as easily fall in the direction of C and D as in any other. Thus, if these buttresses had been cut all the way through, the tree might have fallen toward C and D. However, by being cut only part-way through, C and D were still able to provide enough support for the tree to keep it from falling in their direction. At the same time, the partitions left in buttresses C and D were thin enough so that once the tree had been sufficiently cut through on the opposite side to be ready to fall in that direction, they were unable to hold the tree back and simply tore away as it began to fall.

A tree too large and too heavily buttressed to be cut at ground level was the enormous *shįkįknato* growing in the southwest corner of the experimental plot. It stood some 135 feet tall, and where the buttresses ended and the trunk became cylindrical, about 55 feet above the ground, its diameter was 34.4 inches. At ground level, where the plank buttresses flared the most, the *shikiknato* was more than 12 feet across.

In building a scaffold around a giant tree, the Yanomamö make use of whatever smaller trees may be growing near it, and insert poles in the ground between them where needed for extra support. At a height of 7 or 8 feet above the ground, a number of poles are lashed horizontally to the uprights with vines. This forms the platform on which the men will stand while cutting the forest giant. It will enable them to chop at a height of about 10 feet above the ground. (See Fig. 3.)

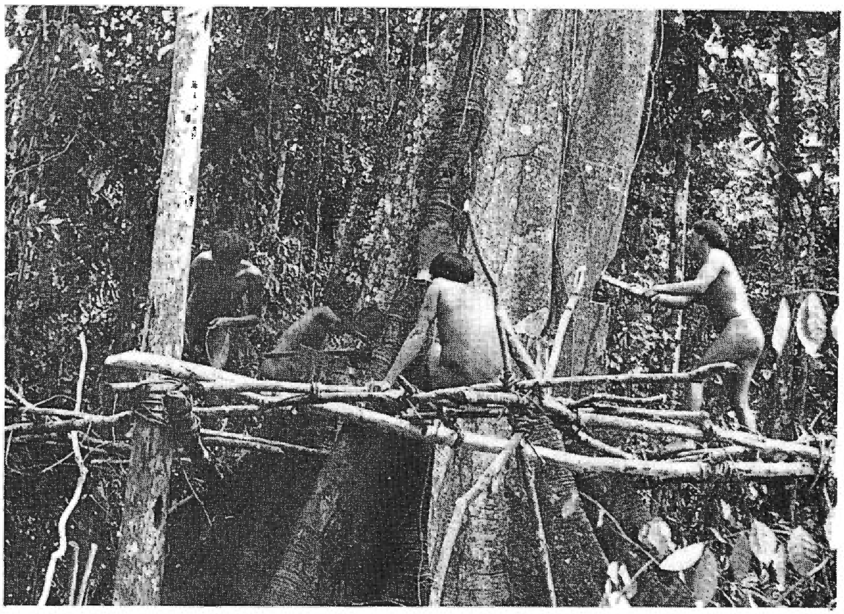

Fig. 3 Yanomamö men standing on a scaffolding and cutting at buttresses on different sides of a large *shikiknato* tree growing in the southwest corner of the experimental plot.

After the scaffolding around the *shikiknato* was finished, one man climbed up on it and began chopping at a buttress on the south side of the tree. Twelve minutes later he was joined by another, who started cutting a second buttress. Although the buttresses were less pronounced at this height than at ground level, they still were quite prominent. Within half an hour, four men were cutting at the tree simultaneously, each working on a different buttress.

Unlike the *motuakehi*, the *shikiknato* did not stand erect but leaned heavily to the north, and the men knew it had to fall in that direction. Accordingly, there was no need to thin the buttresses opposite the fall side, as had been done with the *motuakebi*. Instead, they were cut through, edge-on.

The four men did not all continue cutting at the same time. Each stopped and started again from time to time, as he felt like. Despite its huge size, the tree did not appear to be especially hard to cut, and I later determined that its specific gravity was only .381, so it was, in fact, quite soft[16].

Fig. 4 A Yanomamö standing on the scaffolding and cutting deep into the trunk of the *shįkįknato*, expecting it to fall momentarily.

16. Not having a botanical identification for the *shįkįknato*, I do not know whether it was a soft-wooded primary forest tree, like the silk-cotton tree, *Ceiba pentandra* (specific gravity .44), which also grows to great size, or whether it was a secondary forest tree that had come up in a small clearing years before and survived by out-topping its primary forest neighbors and assuring itself adequate sunlight.

An hour and 16 minutes after they began, having spent almost 3 man-hours cutting the *shikiknato,* the men stopped, expecting the tree to fall. But it did not. Intermittently, one man or another would resume cutting at this or that buttress (see Fig. 4), but the tree still would not fall.

Then, an hour and 31 minutes after the cutting began, a crack was heard. Hopes were raised that now the tree would surely fall, but nothing happened. The men looked up, studied the foliage overhead, and decided that the huge *shikiknato* was being held up by a nearbv tree whose crown abutted it. This supporting tree was a *roakehi* 16.4 inches in diameter which stood some 30 feet outside the plot. While one man started cutting the *roakehi,* another remained on the scaffolding around the *shikiknato* and continued chopping. Eight minutes later another crack was heard in the big tree, and the man on the scaffolding got down, anticipating its fall. But when again nothing happened, one man and then another climbed back onto the scaffolding and resumed cutting at several of the buttresses. This time, though, there was a greater sense of expectation.

About 12 minutes after cutting had started on the *roakehi,* it began to fall with loud cracking sounds. As it fell it only brushed the foliage of the *shikiknato,* and for a moment it looked as if cutting the *roakehi* had failed to produce the desired effect. But a few seconds after the *roakehi* had hit the ground, cracks began to come from the *shikiknato.* This time they were loud enough to signal that it was really going to fall, and it did with a great roar.

At first I had misunderstood the purpose of felling the *roakehi.* The intent, I thought, was to have it hit the *shikiknato* and bring it down, domino fashion. I had not discerned that the crowns of the two trees were sufficiently in contact for the *roakehi* to be holding up the *shikiknato,* and that all that was needed to have the larger tree fall was to fell the smaller one.

Figure 5 shows the cross-section of the *shikiknato* along the plane on which it was cut. One can see that only about 30 percent of the cross-section area of the tree remained uncut when it finally fell. Given the softness of the wood and its distinct inclination, it would surely have fallen with less cutting had it not been for the support of the *roakehi.*

The *shikiknato* fell in the expected direction, about 5°. In doing so, it brought down with it several other trees still standing in the experimental plot [17]. And had they not already been felled by hand, a good many more trees in the plot would have come down with it.

With the felling of the *shikiknato,* the clearing of the experimental plot was completed. In Table 2, I have listed the 35 trees growing in or near the plot which I observed being felled, along with relevant information about each.

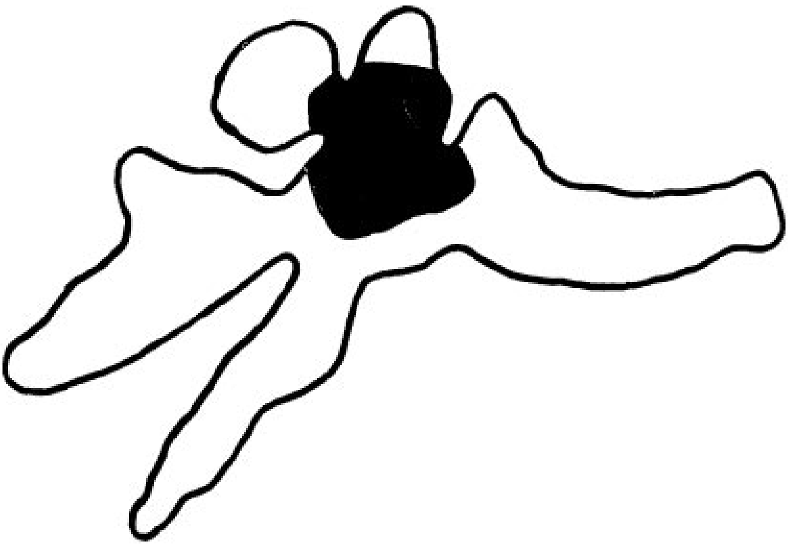

Fig. 5 Cross-section of the *shikiknato* tree along the plane on which it was cut, some 10 feet above the ground. The central area of the trunk, shown in black, was not cut through but broke off when the tree began to fall.

17. This included Tree No. 33, a *yotoknato* 16.1 inches in diameter, that earlier had been partially cut through but which did not fall at the time because it was held up by another tree.

TABLE 2

TREES OBSERVED BEING CUT DOWN IN THE EXPERIMENTAL PLOT AT HASUBÖWATERI, LISTED IN THE ORDER FELLED

Tree No.	*Name*	*Diameter in Inches*	*Specific Gravity*	*Felling Time in Minutes*	*Remarks*
—	roakehi	17.5		10:59	growing outside of plot; inclined away from it
1	roakehi	15.9	.891	47:08	
—	shitibori	8.3	.442	1:32	growing outside of plot; soft wood
34	habromikehi	11.8	.832	12:20	brought another tree down with it
27	masirikohi	11.5	.925	20:54	supported by another tree, so did not fall when expected
III	hotonaokosi	1.1		1:00	felled for easier access to No. 27
66a	warabakohi	10.5	.563	4:34	
56	mahei	18.0	.580	18:45	*"ipïhïwa"*, soft, said about it
55	tǫǫmoro	2.6		:36	cut with a machete
16	roakehi	16.9	.774	19:22	
59	rasharashaknato	1.3			felled for easier access to No. 61
60	washamonamakehi	1.4			felled for easier access to No. 61
65	tǫǫmoro	2.0		1:00	felled for easier access to No. 61
61	paitanari	20.3	.864	48:15	had slight inclination in the direction it fell
63	sibarakohi	17.0	.989	33:38	cutter not as diligent as others
83	nöhötarimi	7.3			hollow; brought down by No. 63 in falling

TABLE 2 (CONTINUACION)

Tree No.	Name	Diameter in Inches	Specific Gravity	Felling Time in Minutes	Remarks
74	taraikehi	6.6			brought down by No. 63
—	roakehi	17.3	.923	23:30	growing outside the plot
107	hikariterimekehi	7.9		1:54	
91	tǫǫmoro	6.3	1.140	6:05	cut by an adolescent
28	motua (kehi)	8.7	.913	11:50	
33	yotoknato	16.1	.826	(6:30)	corrugated surface; cracked but did not fall; held up by another tree
24	masirikohi	9.1		7:22	partially hollow
31	hąshihąshimotariká	2.4		:42	
88	payoarikohi	2.4		:27	
17	hokotomari	4.1	.779	1:02	
111	hąhǫnatahi	4.0	.560	:29	
44	roakanahi	3.6		1:05	
103	opoporeą́hųhi	3.7		:38	
14	tǫǫmoro	7.3	.926	10:56	surrounded by vines; cut by an older man
18	ąri'ahi	24.8	.773	17:33	hollowed inside by termites
—	habromikehi	8.9	.826	4:47	cut on only one side
106	motuakehi	20.4	.914	90:00	had plank buttresses
—	roakehi	16.4	.884	12:00	growing outside the plot, felled to free No. 118; may have been a *yorokosihi* instead
118	shįkįknato	34.4	.381	201:00	had large plank buttresses; scaffolding used in felling it

TIME REQUIRED TO FELL TREES

To the question, "How long did it take the Yanomamö to fell the trees in the experimental plot?" I cannot give a precise answer. During the clearing of the undergrowth I was able to have no more than one individual working at once, and could thus easily time all the work that was done with my stopwatch. However, when it came to felling the trees, I was unable to exercise the same degree of control. A number of men were eager to begin felling trees [18], and after a while I could no longer restrain them. Thus there were times when several men were cutting at once. Nonetheless, I was still able to keep accurate track of the work of the particular individual I was monitoring at any given time.

Altogether, I observed and recorded the felling of only 25 of the 124 trees in the plot [19]. However, that number was large enough to allow me to derive an equation relating felling time to tree diameter. This equation in turn permitted me to estimate the felling times for those trees I had not seen cut, since I had previously measured the diameters of all of them. In devising this formula I was following the lead of William Townsend (1969) who pioneered this approach among the Heve of New Guinea.

Taking the diameters and felling times of the trees I saw felled, I plotted one against the other on logarithmic graph paper. By measuring the slope of the regression line for these points and noting where this line intercepted the *y*-axis, it was possible to derive the equation that best fit the data. This equation is

$$t = .04d^{2.19} \quad , \qquad (1)$$

where t is felling time in minutes and d is diameter in inches. With this equation we can calculate how long it should have taken a Yanomamö to cut down each of the trees whose felling I missed. Then, by adding these estimated felling times to the actual felling times I had recorded, we can ascertain the approximate number of man-hours it took to cut all the trees felled in the experimental plot.

In carrying out this calculation we can make the simplifying as-

18. Most swidden cultivators find felling the trees a zestful activity. Thus, of the Bomagai-Angoiang of highland New Guinea, Clarke (1971: 144) writes, "they very much enjoy the excitement and accomplishment of felling trees". (See also Freeman [1955: 41].)

19. These figures do not imply, however, that the other 95 trees were all cut down with axes while I was not watching. Many smaller ones had previously been cut by machete while the low vegetation was being cleared, while others, somewhat larger in size, were toppled when hit by trees cut by hand.

sumption (which is essentially true) that trees less than 2 inches in diameter were cut down with a machete when the undergrowth was being cleared. Since exactly half of the 124 trees in the plot were less than 2 inches in diameter, that leaves 62 trees with a diameter of 2 inches or more. Of these 62 trees, 25 were felled while I was timing the work, and the total recorded felling time for them was 9.4 man-hours.

Of the 37 trees with a diameter of 2 inches or more that I did not see felled, I at least had a record of their diameters. Thus, bv applying formula (1), it was possible to estimate their individual felling times and then, by simple addition, their combined felling times. These calculations revealed that the total felling time for these 37 trees was 38.8 minutes.

This figure is only about 1/15 of the time it took to fell the trees whose cutting I observed and recorded. The great difference is due to the fact that most of the trees whose felling I was unable to time were relatively small. Indeed, only one of them was more than 10 inches in diameter. We can conclude, then, that in clearing the forest it takes much longer to fell trees of, say, 10 inches or more in diameter than it does to fell those of lesser size. And this is true even though there are a good many more of the latter than there are of the former[20].

Small as it appears, the figure of 38.8 minutes for the calculated felling time of those trees whose cutting I did not observe must be reduced even further. This is because, of the 37 such trees, not all were actually cut by hand. Some of them grew in the path of bigger trees and were toppled by them as they fell. Arbitrarily, then, let us reduce the figure of 38.8 minutes to an even 30 minutes. Now, adding these 30 minutes to the 9.4 hours of observed felling time yields a total 9.9 man-hours as the total time required to fell the trees in the experimental plot. To avoid giving a false impression of precision, let us round off this figure to an even 10 hours.

It will be recalled that the experimental plot was only 1/6 of an acre in size, and my real interest was to determine the time it takes a Yanomamö to fell the trees in a plot of average size, or 1.7 acres. Making the necessary computations we arrive at a figure of 102 man-hours as the total time required to fell the trees in a typical Yanomamö garden plot.

20. In the 1/6-acre forest plot near Hasuböwateri there were 13 trees more than 10 inches in diameter and 49 trees 2 to 10 inches in diameter. In another 1/6-acre forest plot near the village of Tayariteri, there were 12 trees 10 inches of more in diameter and 65 trees 2 to 10 inches in diameter.

That the hardness of a tree should affect its felling time should not surprise anyone. But it was brought home to me with particular vividness shortly after work had begun on the experimental plot. A man who had just felled several trees in the plot told me he was tired and was going to quit. But just as I expected him to head back to the village he picked up his axe and began chopping at a tree outside the plot—a tree which measured fully 8.3 inches in diameter. However, the tree, a *shitibori,* proved to have very soft wood, and in 1 minute and 32 seconds it was on the ground.

This total, though, is something of an underestimate since in arriving at it I have counted only the time actually spent felling trees. A realistic appraisal of forest clearing time, however, must also include the time spent in activities that are not felling in the strict sense. Thus, we must take account of time spent on such things as moving from one tree to the next, considering which way a tree should be felled, sharpening an axe, climbing an adjacent tree to cut away supporting branches, building a scaffold to fell a heavily buttressed tree, and the like. All told, at least an hour should be added to the felling time already calculated for a forest tract the size of the experimental plot. This works out to an additional 10.2 hours of labor for a 1.7-acre plot. Adding these 10.2 hours to the preliminary total of 102 hours obtained above, gives us a total of 112.2 man-hours for the labor required to fell the forest in a Yanomamö garden plot of average size.

Finally, to obtain the total amount of labor required in all phases of land clearance in preparing a garden plot, we must add to these 112.2 hours the 88.9 hours previously calculated for the time it takes to clear the undergrowth. The grand total comes to 201.1 man-hours.

This article is not meant to be a comparative study, but the figures just presented would naturally gain in interest if they were compared with figures for forest clearance from other groups of swidden cultivators. Accordingly, I offer here figures derived from one such group, the Bomagai-Angoiang of highland New Guinea (Clarke 1971: 173). Making the necessary conversions to establish an equivalence in garden size, we can say that to clear a tract of primary forest 1.7 acres in size the Bomagai-Angoiang would spend an average of 42.5 hours cutting the undergrowth and 119 hours felling the trees, making a total of 161.5 man-hours for the entire task.

THE HARDNESS FACTOR

Formula (1) presented above allows us to make a good overall assessment of the time required to fell all the trees in a tract of primary forest. But if we want to estimate the felling time of an individual tree as accurately as possible, more than just its diameter must be known. We must also know its hardness [21].

Given the fact that hardness of wood is important to felling time, two questions arise: first, how do we ascertain the hardness of a tree, and, second, how do we incorporate hardness into our equation? Forestry laboratories measure the hardness of wood by imbedding a .444-inch steel ball half its diameter into a billet of wood and noting the pounds of force it takes to do so (Record 1914: 40). This procedure, which requires very special machinery, is of course beyond the means of the anthropologist. However, it is relatively easy to determine the density of wood. To be sure, density is not the same thing as hardness, but the two are so closely correlated that if we can ascertain the former, we have a reliable measure of the latter.

The density of wood is best expressed by its specific gravity, and this can be determined with no more complicated equipment than an accurate balance scale using a simple procedure described by Record (1914: 136-137). By means of this procedure I ascertained the specific gravity of each of the wood chips I had brought back from the experimental plot at Hasuböwateri (see Table 1). They ranged from .381 for *shikiknato*, the lightest, to 1.029 for one specimen of *toomoro*, the heaviest. The average specific gravity of the trees felled in the plot was .81.

The procedure I chose for incorporating hardness of wood into the equation for felling time was as follows. After determining the specific gravity of a given tree, I divided this figure by the average specific gravity of the trees in the plot, namely, .81. This quotient I called the *hardness factor*. For trees denser than average, the hardness factor will be greater than 1, while for those lighter than average, it will be less than 1. For instance, if the specific gravity of a certain tree is, say, .94, its hardness factor will be .94/.81, or 1.16. On the other hand, if it is lighter than average, with a specific gravity of, say, .47, its hardness factor will be .47/.81, which is .58. The original felling time obtained for a tree of a given diameter by means of formula (1) is then multiplied by the hardness factor to give a more precise estimate of its actual felling time.

21. In an earlier paper, I showed that by taking accout of the hardness of wood, a much greater convergence could be obtained for the times predicted by Townsend's (1969: 203) formula for Heve tree felling with a stone adze, and the formula I devised for Yanomamö tree felling with a stone axe (Carneiro 1979: 50-53).

In order to get a clearer notion of how the use of this hardness factor affects the results of our estimates of felling time, let us work through a couple of examples. Suppose we are felling a tree 14 inches in diameter of average hardness, that is, having a specific gravity of .81. The calculation will read

$$t = .04 \times 14^{2.19} \times .81/.81 \ ,$$

which works out to an estimated felling time of 12.9 minutes. Suppose now that the hardness of this 14-inch tree is .94 instead of .81, yielding a hardness factor of 1.16. Its felling time would then be 12.9 minutes x 1.16, which is 15 minutes. If, on the other hand, the 14-inch tree had a specific gravity of .47, so that its hardness factor was .58, its felling time would be 7.5 minutes.

We see, then, that taking account of a tree's hardness can make a considerable difference in its estimated felling time. If our hardness factor is an accurate measure of the effect of hardness of wood on felling time, we can deduce from the examples worked out above that, holding diameter constant, a tree twice as hard as another will take twice as long to fell.

That using a hardness factor in the equation will increase the accuracy of predicted felling times is not just a matter of theory. It is demonstrated empirically by the figures shown in Table 3. Of the 14 trees listed here, the predicted felling times of 11 were improved by correcting for hardness.

It should be noted, though, that the way in which hardness has been incorporated into the formula is perhaps too simple. A more sophisticated way of doing so might increase predictability even more [22]. At least, though, the present correction is clearly a step in the right direction.

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22. For example, squaring the specific gravity of a tree and dividing the result by the square of the average specific gravity, gives a hardness factor which, for trees harder than average, definitely improves predictions of felling time. However, this squaring procedure seems to worsen the prediction of felling times of most trees that are softer than average.

TABLE 3

EFFECT ON PREDICTED FELLING TIME PRODUCED BY TAKING THE HARDNESS OF INDIVIDUAL TREES INTO ACCOUNT. DATA FROM EXPERIMENTAL PLOT AT HASUBÖWATERI

				Predicted Felling Time in Minutes			*Improvement (+) or Worsening (—) of Prediction*
Tree No.	*Name*	*Diameter in Inches*	*Specific Gravity*	*Hardness Neglected*	*Hardness Considered*	*Actual Felling Time in Minutes*	*with Hardness Considered*
63	sibarakohi	17.0	.989	19.8	24.1	33.6	+4.3
27	masirikohi	11.5	.925	8.4	9.6	20.9	+1.2
61	paitanari	20.3	.864	29.2	30.2	48.3	+1.0
34	habromikehi	11.8	.832	8.9	9.1	12.3	+0.2
17	hokotomari	4.1	.779	0.9	0.9	1.0	0
56	mahei	18.0	.580	22.4	16.1	18.8	+0.9
66a	warabakohi	10.5	.563	6.9	4.8	4.6	+2.1
111	hąhǫnatahi	4.0	.560	0.8	0.6	0.5	+0.2
—	shitibori	8.3	.442	4.1	2.2	1.5	+1.9
1	roakehi	15.9	.891	17.1	18.8	47.1	+1.7
16	roakehi	16.9	.774	19.5	18.6	19.4	—0.7
28	motua(kehi)	8.7	.913	4.6	5.2	11.8	+0.6
14	tǫǫmoro	7.3	.926	3.1	3.5	10.9	+0.4
—	habromikehi	8.9	.826	4.8	4.9	4.8	—0.1

GENERAL APPLICABILITY

Having reached this point we may now raise the question, "Does the formula for tree felling derived from the Yanomamö experiment apply to all swidden cultivators?" Three months after leaving the Yanomamö I carried out a similar experiment with the Kuikuru of central Brazil. This experiment was more limited and I was able to measure the felling time of only 11 trees. However, the equation relating felling time to tree diameter obtained from these 11 trees was

$$t = .008d^{2.39} \qquad (2)$$

This equation differs significantly from the one obtained from Yanomamö data, as one can readily see by comparing the felling times for trees of various diameters shown in Table 4.

TABLE 4

PREDICTED FELLING TIMES FOR TREES OF VARIOUS DIAMETERS ACCORDING TO FORMULAS WORKED OUT AMONG THE YANOMAMÖ AND KUIKURU INDIANS

Diameter of Tree in Inches	*Predicted Felling Time, Yanomamö Formula* $t = 0.42^{2.19}$	*Predicted Felling Time, Kuikuru Formula* $t = .008d^{2.39}$
5	1.4 mins.	0.4 mins.
10	6.2 mins.	2.0 mins.
15	15.1 mins.	5.2 mins.
20	28.3 mins.	10.3 mins.
25	46.1 mins.	17.5 mins.
30	68.7 mins.	27.1 mins.

Unquestionably, the Kuikuru appear to fell trees much faster than the Yanomamö. But is this difference real? Is it possible that, since it is based on only 11 trees (as against 25 for the Yanomamö), the Kuikuru formula is unreliable and the differences in felling times are spurious? I doubt this very much. I think the differences are genuine. The Kuikuru *do* fell trees faster than the Yanomamö. And two things seem to account for this difference. First of all, the Kuikuru are bigger and stronger than the Yanomamö, outweighing them by perhaps 40 or 50 pounds per man. This extra weight cannot help but give their blows greater force. And indeed, as I watched the Kuikuru felling trees I had the distinct impression that they chopped harder than the Yanomamö.

The two groups also differ in their mode of chopping. The Yanomamö chop in short bursts followed by periods of rest. The Kuikuru, on the other hand, while they may not chop quite as fast as the Yanomamö, chop longer without resting. In fact if a tree is not too big, a Kuikuru may chop at it without stopping until it falls.

Despite overall differences in felling times, it is significant that the exponents of the two equations, 2.19 for the Yanomamö and 2.39 for the Kuikuru, are rather close [23]. However, they differ significantly from the exponent of the formula I have presented elsewhere (Carneiro 1979: 48) relating felling time to tree diameter among the Yanomamö when a tree is being felled with a stone axe. This formula is

$$t = 2.3d^3 \,, \qquad (3)$$

where *t* is the felling time in hours, and *d* is the diameter of the tree in feet. That the exponent of this equation came out to be 3, I attributed to the geometric principle that volume increases as the cube of linear dimensions. (Volume in this case is the amount of wood that must be cut from a tree in order to fell it, while the linear dimension is the diameter of the tree.).

But if the volume of wood that must be cut away from a tree in felling it with a stone axe increases as the cube of its diameter, why does it fail to do so when the tree is felled with a steel axe? Why were the exponents in the two steel axe formulas substantially less than 3? At first, I was sure I had made an error in calculating these two exponents, and that they should have come out to be 3, or something very close to it. But a recalculation showed that the lower values for the exponents were correct. Yet, why should these exponents be as low as 2.19 and 2.39 instead of 3? How are we to account for this deviation from expectations?

The answer lies, I think, in the differences in shape of the cuts made in a tree being felled with a stone axe and one being felled with

23. The marked difference in felling time between the two groups, represented in the equations, is due more to the difference in their coefficients, .04 for the Yanomamö, and .008 for the Kuikuru.

a steel axe. First of all, in felling a tree with a stone axe the Yanomamö, like Neolithic peoples generally, cut all the way around the trunk, much as a beaver does (see, e.g., Ehrenreich [1929: 267-268]). With this technique, a greater volume of wood must be cut from a tree to make it fall than if a steel axe is used and the tree is cut on opposite sides only. Nevertheless, I believe that this particular difference in cutting technique between the stone axe and the steel axe is reflected only in the coefficients of the respective formulas and not in their exponents. The differences in the values of the exponents is accounted for by still another difference in the mode of cutting. This difference is best represented graphically (Fig. 6). In this schematic drawing we see, in profile, the angle of the cleft made in felling successively larger trees with a stone axe (a), and with a steel axe (b).

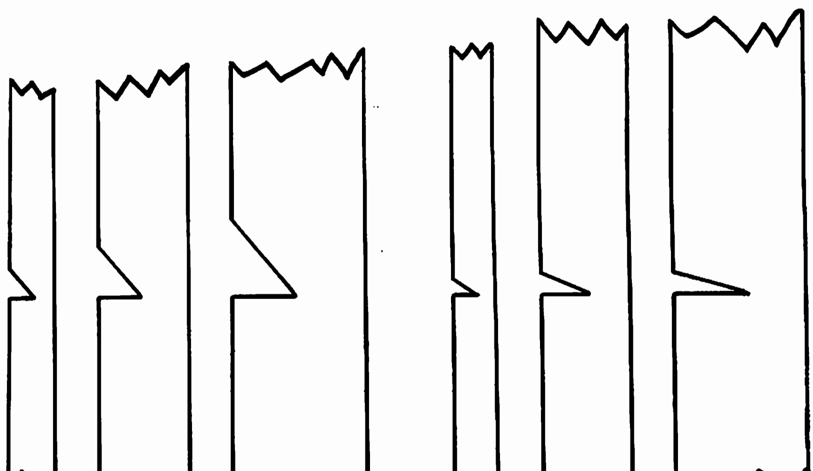

Fig. 6 Schematic diagram comparing the angles of the clefts made in cutting trees of successively greater diameters with a stone axe, *a*, and a steel axe, *b*. The angles of the former stay the same, while those of the latter become progressively smaller.

One can readily see that this angle is larger in trees cut with a stone axe. But not only is the angle larger; it also remains essentially the same, regardless of the size of the tree. When trees are being cut with a steel axe, however, the angle of the cleft is smaller to begin with, and becomes even smaller as the diameter of the tree increases.

The reason the angle of the cleft is larger when a stone axe is used, and remains about as large, is that the stone axe has a thick blade and a bulbous head, and so must have a wide aperture to cut into or its sides will bind and it will fail to cut effectively (Carneiro 1979: 35-37). Consequently, every time the cleft is to be deepened appreciably, it must first be widened correspondingly. A steel axe, on the other hand, having a thinner edge, can cut effectively into a narrow cleft. Moreover, in felling successively larger trees, this cleft need not be enlarged in the same proportion as it is deepened.

If this line of argument is correct, in felling successively larger trees with a stone axe the ratio of the height of the cut to its depth remains the same. And if this is so, we can prove geometrically that the volume of wood that must be cut out of a tree in order to fell it will increase as the cube of its diameter (Carneiro 1979: 44-48). However, when trees are felled with a steel axe, the ratio of the height of the cut to its depth is not fixed but becomes smaller as the diameter of the tree becomes larger. (This can be seen in Fig. 6b.)

The fact that the ratio of the height of the cleft to its depth decreases with the size of the tree when it is felled with a steel axe means that the volume of wood that must be cut from it increases as a power less than the cube of its diameter. For the Yanomamö formula this power is 2.19, while for the Kuikuru formula it is 2.39.

That in felling a tree with a stone axe the angle of the cleft stays the same, regardless of the size of the tree, was an assumption I made while devising the formula for stone axe felling among the Yanomamö (Carneiro 1979: 45-46). But since I had only a single tree felling to go by, it was a surmise rather than an observed fact. In retrospect, I would say that even in stone axe felling, the angle of the cleft is probably not the same for trees of various sizes. It may well diminish slightly with an increase in tree diameter, although certainly not by as much as when a steel axe is used. If this is true, then the exponent in the stone axe equation should be something less than 3. A value of perhaps 2.7 might be closer to the fact. Using this value instead, the formula relating felling time to tree diameter when the cutting is done with a stone axe becomes

$$t = 2.3d^{2.7} \quad . \tag{4}$$

FELLING TIMES COMPARED

Now that we are more aware of the uncertainties in our equations, and thus readier to appreciate the margin of error involved in any calculation based on them, let us nonetheless proceed to use them in comparing the expected felling times for trees of various diameters when cut with the two types of implement. The data used in these calculations are those I obtained among the Yanomamö.

To determine felling time with a steel axe, I will use the equation, $t = .04d^{2.19}$. To determine felling time with a stone axe, I will make use of the basic equation $t = 2.3d^3$, as well as the proposed revision, $t = 2.3d^{2.7}$. However, since in the latter equations *t* is expressed in hours and *d* in feet, while in our steel axe equation *t* is in minutes and *d* in inches, we need to convert them into equivalent units. Accordingly, I have modified the two stone axe formulas to read in minutes and inches so that they now stand

$$t = .083d^3. \tag{5}$$

and

$$t = .1683d^{2.7} \quad . \tag{6}$$

The immediate results obtained by applying these formulas to trees of various diameters will be multiplied by the hardness factors appropriate to each equation, h/.81 in the case of steel axe felling, and 1.3h in the case of stone axe felling [24]. In the example worked out below, I have arbitrarily assigned a specific gravity of 0.6 to the hypothetical trees being felled, making them about as hard as oak. The results of these calculations appear in Table 5.

24. The reason a hardness factor of 1.3h is used with the stone formula is that the single tree on whose felling the formula is based, which thus provides our only measure of "average" hardness, had a specific gravity of .76. Multiplying the initial results of the stone axe equation by 1.3h will have the effect of raising the estimated felling time if the specific gravity of a tree is more than .76, lowering it if it is less than .76, and leaving it unaffected if it is the same (1.3 x .76 = 1).

TABLE 5

RELATIVE FELLING TIMES FOR TREES OF VARIOUS SIZES AND A SPECIFIC GRAVITY OF 0.6

Diameter of Tree in Inches	Estimated Felling Time in Hours		
	With a Stone Axe		*With a Steel Axe*
	$t = .083d^3$	$t = .1683d^{2.7}$	$t = .04d^{2.19}$
6	0.2	0.2	0.02
12	1.8	1.8	0.11
18	6.1	5.4	0.28
24	14.4	11.7	0.52
30	28.1	21.3	0.85
36	48.5	34.8	1.26
48	115.0	75.8	2.37

Even though the formulas shown above yield answers in minutes, the figures in the three right-hand columns have been converted into hours so as to avoid the large numbers that would result if the stone-axe felling times of the larger trees were expressed in minutes.

A mere glance at this table shows that it takes much longer to fell a tree with a stone axe than with a steel one. But what is the ratio between these felling times? On the basis of his work among the Heve, Townsend (1969: 204) concluded that it took 4.4 times longer to fell the forest with a stone axe (actually, an adze) than with a steel axe. Implicit in Townsend's discussion is the belief that the ratio of 4.4 to 1 holds true regardless of the size of the trees being felled. However, the figures in Table 5 point to a different conclusion. From these figures we can construct Table 6, which shows that the ratio in felling times does not stay constant at all, but increases strikingly with tree size.

Even for trees 6 inches in diameter (the smallest ones listed in Table 6), the ratio of felling time for the stone axe vs. the steel axe is 10 to 1, which is substantially higher than Townsend's 4.4 to 1. Only when we calculated this ratio for even smaller trees do we begin to get figures comparable to Townsend's. Thus, for a tree 3 inches in diameter the ratio of felling times is 5 to 1, and for a tree 2 inches in diameter it is 3.7 to 1.

TABLE 6

CALCULATED RATIO OF FELLING TIMES FOR TREES OF VARIOUS DIAMETERS CUT WITH A STONE AXE ($t = .1683d^{2.7}$) AND A STEEL AXE ($t = 04d^{2.19}$)

Diameter of Tree in Inches	*Ratio of Felling Time, Stone to Steel*
6	10 to 1
12	16 to 1
18	19 to 1
24	23 to 1
30	25 to 1
36	28 to 1
48	32 to 1

The reason behind the great discrepancy between Townsend's ratio and ours now begins to emerge. His tree felling experiment must have been conducted in a forest with very few large trees [25]. This supposition is borne out when we examine the data plotted on his graphs (Townsend 1969: 201, 203). Of the 91 trees felled by the Heve in the experiment, the largest was only 15.4 inches in diameter, and only 6 were more than 10 inches in diameter. Moreover, most of the trees were considerably smaller than 6 inches in diameter.

To bolster the validity of his felling ratio, Townsend cited the work of Richard Salisbury among the Siane of the New Guinea highlands. Salisbury (1962: 219-220) was told by his informants that in the days of the stone axe it took 3 to 4 times longer to clear a garden plot than it does today with a steel axe. But here again, the reason for the low ratio in felling times compared to ours surely reflects the size of the trees involved. The Siane live at an altitude of 6,000 to 7,000 feet, where the trees are diminished in size and the forest is dominated by the slim, pine-like casuarina (Salisbury 1962: 9-11).

On the basis of the evidence available I am ready to assert that in an area of lowland primary forest, where the trees are substantially

25. Elsewhere (Carneiro 1979: 51) I have presented some evidence for believing that the trees which the Heve felled for Townsend formed part of a secondary rather than a primary forest, where trees tend to be relatively small.

larger than in the forests of the Heve or Siane, Townsend's and Salisbury's ratios of 4.4 to 1 and 3.5 to 1 respectively will not hold. The ratios will be significantly higher.

In support of this assertion let us consider the following case. Suppose we are dealing with a garden plot 1.7 acres in size that is to be cleared in an area of forest having the same distribution of tree sizes as in the experimental plot at Hasuböwateri. Assuming that all trees 2 inches or more in diameter are felled with the stone axe, and applying the formula, $t = .1683d^{2.7}$, we get a total of 1,229.3 as the number of man-hours required to fell the trees in this plot. On the other hand, felling the same trees with a steel axe would take only 64.2 man-hours. The ratio of stone axe felling to steel axe felling is then 19 to 1.

It is clear from these calculations that if all the trees in the forest tract are to be felled with a stone axe, the labor involved in clearing a garden plot is enormous. Indeed, it is quite beyond the capacity of a swidden cultivator to perform. Assuming a 5-hour work day, which is more or less typical for Amazonian cultivators, 1,229.3 man-hours represents 246 man-days, which in turn represents some 8 man-months of labor. Yet we know that under aboriginal conditions, tree felling was limited to the period between the end of one rainy season and the beginning of the next, a period of no more than about 5 months. And of course not every day of that period could be devoted to felling trees. Thus, if a plot was to be made ready to burn before the onset of the next rains, the calculated labor of clearing the forest had to be reduced in some way. How was it done?

The first thing to be noted in trying to answer this question is that the greatest proportion of the work that goes into clearing the forest is taken up by the felling of the large trees which are relatively few in number. In our hypothetical 1.7-acre plot, there would be some 632 trees 2 inches or more in diameter, of which only 20 would be 2 feet or more in diameter. Yet the labor of felling these 20 trees would amount to 569.5 of the total of 1,229.3 man-hours of felling time, or 46.3 percent. Now, if all trees 2 feet or more in diameter were not felled but simply girdled, so they would shed their leaves and cast less shade on the growing crops, the work of forest clearance would be substantially reduced. It would then take 659.8 man-hours to fell the rest of the trees which, compared to the 64.2 man-hours of tree felling with a steel axe, would lower the ratio between them to about 10 to 1.

What, in fact, did Amazonian cultivators do aboriginally about felling the really large trees? To begin with, we know from a number of early ethnographic sources that swidden cultivators did not necessarily shrink from the task of felling the forest giants. Thus, Father Gumilla (1963: 492), writing of the Orinoco, and Joseph Skinner (1805: 435 n.), writing of the Peruvian Montaña, each reported hearing that in the days of the stone axe some of the trees tackled took two months to fell.

Nevertheless, cutting down a huge tree must have been something to avoid if at all possible, and there were ways of doing so, or at least of lessening the work involved. Girdling a tree, mentioned above, was certainly widely done. Somewhere between outright felling and girdling was the practice of building a fire around a tree and when the fire had died down, hacking out the charred parts, which were much softer than the green wood. The procedure was repeated until the tree fell. This technique was widespread in Amazonia [26]. It was used by the Yanomamö (Chagnon 1968: 33; Barandiarán 1967: 26), as well as by the Kuikuru and Amahuaca (Carneiro 1974: 114). It has also been reported for the Yamamadí and the tribes of the upper Uaupés (Baldus 1970: 178-179). Some tribes, such as the Erigpagtsá (Schultz 1964: 244-245), Tapirapé and Tembé (Baldus 1970: 178-179) simply built a fire around a large tree and kept adding fuel to it until, after 3 or 4 days, enough of the trunk had been burned through for the tree to fall.

It is also very likely that during the days of the stone axe greater and more controlled use was made of the driving tree fall. Smaller trees in the path of a larger one may have been partly cut through so they would break off and topple over more readily when hit by a larger falling one. This practice was still being used by the Tapirapé in the mid-twentieth century despite their adoption of the steel axe (Baldus 1970: 178).

There can be no doubt that the use of such methods as these would have greatly reduced the time, and certainly the effort, required in felling trees of great girth. But because of the uncertainties in knowing the extent to which they were used, and how much labor they saved, it is impossible to estimate with anything like precision how long it took an Amazonian cultivator to clear a forest plot aboriginally. It seems safe to say, though, that despite the savings in labor effected by the use of these auxiliary techniques, forest clearance remained a burdensome and

26. Emilio Göldi (1906: 443-444) has left us an interesting description of the way in which this technique was practiced by one Amazonian tribe which, unfortunately, he failed to identify. First, a ring of bark was removed from the trunk of the tree so that the sap would drain out, killing the tree. When the tree was dead and dry, the groove cut through the bark was deepened into the wood below, which was crushed and splintered with the stone axe so it would burn more readily. Palm nuts were then introduced into this groove and lighted. This permitted a carefully restricted burning which left a charred band of wood ready to be chopped out.

time-consuming task. Indeed, it must have taken a good 7 or 8 times longer to perform in the days of the stone axe than it did once the steel axe was adopted.

CONCLUSION

In this paper I have presented some observations, calculations, and speculations about forest clearance among the Yanomamö. I have also tried to compare the labor of felling trees with the stone axe and the steel axe. The results presented here are still tentative and require corroboration. This paper, then, is an invitation to others to undertake similar experiments and calculations so that eventually we will be able to gauge, with some precision, the labor of Neolithic man in clearing the forest before planting his crops.

ABSTRACT

This paper describes an experiment in forest clearance carried out in the Yanomamö village of Hasuböwateri in 1975. Several men were asked to clear the undergrowth and fell the trees in a small experimental plot. Their method of clearance was observed, and the time required in these operations was recorded. From these observations an estimate was made of the time it takes the Yanomamö to clear a garden plot of average size. From observed felling times, a formula was constructed which permits one to predict the felling time of a tree from its diameter. It was found that the accuracy of this formula could be improved if a measure of the hardness of the tree being felled was incorporated into it. The results obtained from this formula were compared with those of another study made in the same Yanomamö village in which a formula was devised for predicting tree felling time when the tool used was a stone axe. The comparison showed that it takes about 8 to 10 times longer to clear the forest with a stone axe than with a steel one.

RESUMEN

Esta contribución describe un experimento de desmonte realizado en 1975 en la comunidad Yanomamö de Hasuböwateri. Pedimos a varios hombres que limpiaran la maleza y que talaran los árboles de una pequeña parcela experimental. Observamos el método de desmonte y registramos el tiempo requerido en estas operaciones, lo que nos permitió hacer un estimado del tiempo que emplean los Yanomamö para talar

una parcela de tamaño promedio. A partir de estas observaciones elaboramos una fórmula para calcular el tiempo requerido para tumbar un árbol basándonos en el grosor de su diámetro. Comprobamos, además, que la precisión de la misma mejoraba si tomábamos en cuenta el grado de dureza del árbol. Los resultados obtenidos a partir de esta fórmula los comparamos con los de otro estudio realizado en la misma zona Yanomamö; para este caso habíamos elaborado una fórmula que nos permitiera conocer de antemano cuánto tiempo se requiere para tumbar un árbol con hacha de piedra. La comparación demuestra que desmontar la selva con esta última toma aproximadamente de 8 a 10 veces más tiempo que haciéndolo con hacha de acero.

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