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Decisions of Cattle Herdsmen in Burkina Faso and Optimal Foraging Models

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Models of optimal foraging theory are used to evaluate the decisions of a sedentary herdsman and his family in Burkina Faso concerning the movement of his cattle from pasture to pasture. Generally, such models describe exploitation at the patch level, but are inadequate at higher levels. The herdsmen in the study area are generally sedentary, and their strategy of exploitation appears to be characterized by planning at least in terms of a whole day and minimizing daily travel time among fields. In conjuction with this conclusion a modified optimization model is proposed. We conclude that optimal foraging models are useful in interpreting and understanding the rules governing the movements of traditional West African herdsmen when so modified, but that more data are needed to develop and test these models further.

KEY WORDS: optimal foraging; grazing; pastoralism; sedentary husbandry; herd movement, West Africa.

INTRODUCTION

In this paper, we use theoretical models developed by biologists to explain the foraging behavior of animals to analyze the movements of a sedentary West African herdsman who moves daily with his cattle between grazing grounds, and has to make decisions regarding which fields to visit and the amount of time to spend in each one before moving on. The biological models, which can be used to judge and model these decisions, form part of optimal foraging theory (see Schoener, 1971; Pyke *et al.*, 1977; Stephens and Krebs, 1986). Briefly stated, foraging is optimal when the "economic"

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return of a certain foraging strategy is highest in relation to its costs as compared with other foraging strateiges. "Economic" returns and costs can be assessed in terms of energy, but also when dealing with humans, in terms of money.

Optimal foraging models have proved fruitful in interpreting food-collecting strategies of hunter–gatherers (see Winterhalder and Smith, 1981; Smith, 1983; Keegan, 1986; Pate, 1986; Hill *et al.,* 1987). Indeed, similar models have long been used in studies regarding the economic behavior of consumers in western society (Rapport and Turner, 1977). However, a herdsman's movements are complex, and many factors beyond the scope of the theoretical models also play a role in decisions he makes. Profit maximization alone does not determine his decisions; social contacts with family and friends, or evading less-liked neighbors may also determine movement patterns (Gulliver, 1975). It is clear that decision making is a complicated process, influenced by many factors. We hope that the present paper contributes to the understanding of some forms of traditional West African husbandry, and can offer a framework to interpret the strategies of herdsmen.

Traditional West African husbandry is normally risky: long periods of drought can cause drastic reductions of the herd, jeopardizing both milk and calf production. Clearly, one of the main aims of the herdsman is to minimize the risk of production dropping below subsistence level (Dahl and Hjort, 1976; Scott, 1976; Rapport and Turner, 1977; Konczacki, 1978; Menzel and Wyers, 1981; Jahnke, 1982; Smith, 1983; Toulmin, 1983). It is also known that humans change their decisions when they are confronted with a stochastic environment (Keeney and Raiffa, 1976; see also Stephens and Charnov, 1982). Because their decisions and their willingness to accept risks is dependent on the reward and the variance and valuation of the reward (Keeney and Raiffa, 1976), stochastic events, such as rainfall pattern (Prins and Loth, 1988) or vegetation production, can influence the movement strategy of an African herdsman.

Finding an optimal decision resulting in maximization of profit is often very difficult. However, a strategy aimed only at satisfying certain minimal requirements requires a less demanding decision-making model, and it is likely that such strategies can be developed more easily (Rapport and Turner, 1977; Pottinger, 1983). Likewise, we think it unreasonable to assume that herdsmen possess perfect information regarding all options and regarding all consequences of their decisions; moreover, their production occurs indirectly through their cattle. Thus, "rules of thumb" (Janetos and Cole, 1981) could be important to guide them when making decisions, and it appears reasonable to assume that herdsmen make approximations. Lack of perfect knowledge might explain discrepancies between observed decisions and theoretically optimal ones.

Is it acceptable to use optimal foraging models to analyze decisions of West African herdsmen? The herdsmen must maintain a certain level of herd production simply for subsistence, and bad herd management can reduce herd production, thus jeopardizing the survival of the owners. It seems obvious that decisions regarding herd movements are subject to penalties and rewards, as "wrong" decisions can have important implications for the welfare of the family. We assume that herdsmen are able to calculate the costs of investment and the potential economic returns associated with their decisions, and base their decisions on the outcome of the calculation. It appears reasonable to assume that herdsmen, especially when engaged in sedentary husbandry, have a vast knowledge about the quality of different pastures within their home range, and also about the "profits" to be expected in these pastures. Apart from making assessments about the present state of affairs in "their" territory, they can be expected to have experiences and knowledge about the past, facilitating judgment of the present situation. Finally, they are certainly able to communicate with their neighbors and other herdsmen about their judgments and opinions. It thus appears reasonable to assume that herdsmen have the opportunity to behave rationally (as used in economic terminology), and this assumption justifies the use of optimal foraging models as a framework within which to analyze their decisions.

In order to apply optimal foraging models to decisions of West African herdsmen, the goal the herdsman strives for must first be defined: phrased in optimal foraging theory terms, we have to determine the "currency" herdsmen try to optimize. Second, we must carry out cost-benefit analyses regarding the decisions of these herdsmen when they move from grazing ground to grazing ground. Finally, we have to determine the optimal decision associated with each of these cost-benefit analyses (see Schoener, 1971).

The Goal of Production and the Currency of the Herdsman

The goal of production determines the decisions to be taken. As the main goals of production in West African extensive cattle husbandry are both growth of the herd and production of milk, the herds are mainly comprised of cows. Under this mode of production, the herd can continue to grow and cows are generally not sold for meat (Dahl and Hjort, 1976; Crotty, 1980). Other goals, such as status, possession of (financial) reserves, or the possibility of paying bridewealth may be achieved as a consequence of successful herd management (Toulmin, 1983).

We can therefore assume that the production of milk and calves comprises the currency that the herdsman tries to maximize. The general condition of cows is a good predictor for the pregnancy rate of the herd, and cows in a better condition produce more calves (Herd and Sprott, 1986), have a longer lactation period after each parturition, and produce more milk per day (Barrett and Larkin, 1979). The most important factor promoting good condition is food intake (Prins and Beekman, 1989). Food intake can be expressed as the net energy intake per time in animals (Schoener, 1971; Pyke *et al.,* 1977; Krebs and McCleery, 1984; Pianka, 1978; Winterhalder, 1981). Hence, herdsmen behave optimally when they steer their cattle to areas yielding the greatest food intake.

The Models: Optimal Duration of Grazing in a Patch

Biologists call (potentially) acceptable foraging areas within a discontinous environment "patches" (Pianka, 1978). Patch identification and size depend on the type of forager; for example, a patch is different for a guinea fowl as opposed to a cow. Grazing grounds visited by herdsmen can be seen as patches. From the herdsmen's perspective (and in relation to herd size), patch sizes should be viewed on approximately a hectare scale.

Charnov (1976) developed a theoretical model that predicts the residence time of a forager in a patch that maximizes intake. In this model, the energy intake per time unit is viewed in relation to travel time (t = the amount of time to reach the patch visited) and residence time (T = the amount of time spent in the patch; Fig. 1a). The total amount of food in a patch will decrease after a forager has entered a patch. There will be more food when the animal enters a patch, and intake will be high at the start of the exploitation of the patch and will subsequently decrease. The point in time where the maximum energy intake per time unit is reached is the optimal residence time (T_{opt}); (Fig. 1a). If patches are equal regarding the food offered, then an optimal forager will exploit each patch so that he leaves it at this optimal residence time.

The optimal residence time (T_{opt}), at which maximum intake per time unit is reached, depends on the amount of travel time (t_x) invested. Traveling longer to a patch will result in a longer optimal residence time, because the maximal intake per time unit is reached at a later point in time. According to Charnov's hypothesis, an asymptotic relationship exists between travel time and optimal residence time (Fig. 1b). If grazing areas are uniform with regard to size and quantity and quality of the available food, and if herdsmen exploit these pastures optimally, then the following hypothesis can be presented.

Hypothesis 1. There is an asymptotic relation between travel time and foraging time in the exploitation of grazing areas.

Patches can differ in the amount of available food. The model as outlined previously does not describe the optimal residence time for these patches. The total foraging area comprising all patches contains a certain amount of food, which can be exploited by investing a certain amount of total travel

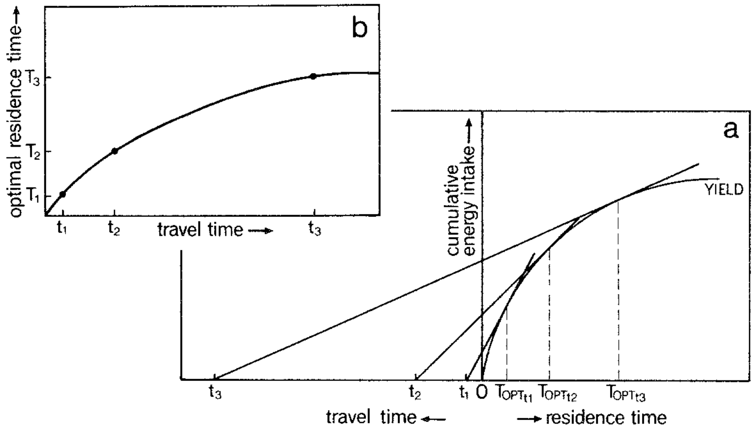


Fig. 1. The energy intake curve over time in a patch. Intake diminishes over time because food depression takes place. The optimal residence time in the patch (T_{opt}) at which intake per total time invested is at a maximum depends on the travel time (t_x), as shown by the optimal exploitation of the same patch when travel times differ. (a) Three travel times are given, t_1, t_2, and t_3. With a longer travel time, the maximum intake rate is reached at a later residence time, T_{opt}. (b) The relation between travel time and optimal residence time is shown based on the curves in (a).

time plus total residence time. If the total amount of food in that area is divided by the total amount of time invested, then we obtain a measure of average quality for the whole area. The forager behaves optimally if he leaves a patch when his intake rate in that particular patch becomes equal to the average value of the whole area; he then moves to another (now better) patch (see Fig. 2). This is called the "marginal value theorem" (MVT; Charnov, 1976). The MVT can be used to analyze herdsmen's movement strategies. If the intake rate of his cattle decreases to below the average intake rate of the whole area, the herdsman behaves optimally if he then moves to a new patch.

Thus, if grazing areas are not uniform, the moment of departure is described by the following hypothesis:

Hypothesis 2. The optimal time of departure from a field is when the total food intake in relation to the amount of invested travel time plus grazing time becomes equal to the average intake rate, i.e., the amount of ingested food in relation to the total amount of invested time, for the whole area that is being exploited by the herdsman and his cattle.

Dynamic Models vs. Static Models

It is typical of optimal foraging models that they try to reach an optimal solution in order to maximize the chosen currency without taking into account other factors that also might influence that currency (see Katz, 1974;

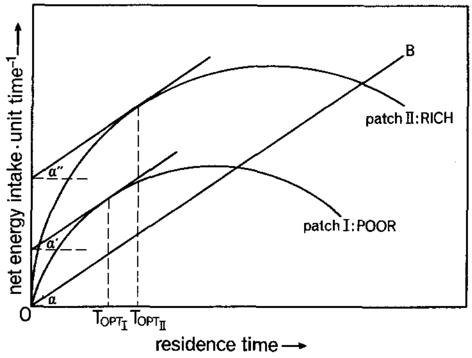


Fig. 2. The energy intake curves per total time, i.e., travel time plus residence time, in a "rich" and in a "poor" patch. In the figure, the straight line O-B represents the average intake rate in the total area. The optimal residence time is reached when the intake rate in a patch equals the average intake rate in the total area (from Charnov, 1976). The angles *a*, *a*', and *a*" are equal.

Houston, 1980; Krebs and McCleery, 1984). A simple approach to avoid this problem is to define some constraints beyond which no solution can be formulated, such as rumen size as a constraint on food intake in the case of ruminants, or the necessity to go home before nightfall. A dynamic approach is necessary in a more problematic situation when the chosen currency changes over time. Within a time series, herdsmen have to maximize the intake of their cattle, they have to make sure that their cattle drink enough and often enough, and they have to prevent their cattle straying into fields that have not yet been harvested.

Also important is the choice of the time scale on which the effects of the behavior on the chosen currency have to be measured (Katz, 1974; Pyke *et al.,* 1977; Graig *et al.,* 1979; Krebs *et al.,* 1981). In a static model, the effect on the currency is described in a single time period, and in these models the different time periods do not bear on each other (Katz, 1974). In a dynamic long-term optimization model, it is assumed that a "state at any given time is influenced by events at other times" (Graig *et al.,* 1979, p. 32). Hence, the time scale over which behavior is studied has to be much longer than in static models. A dynamic long-term strategy can take into account changes in availability of food over many days or even seasons. This is why it is believed that it is better for a forager to have a long-term dynamic strategy than a static optimization strategy, if that forager lives in a regularly fluctuating environment (Katz, 1974; Belovsky, 1986).

Humans are able to take into account long-term changes and the future consequences of their behavior. For example, transhumance is a long-term dynamic strategy as is the sale of cattle by people who anticipate their animals will die if a hunger period continues. It is important to realize that the application of a long-term dynamic strategy can cause a short-term strategy to be sub-optimal, and that the long-term goal can override the short-term one. Examples would be the sub-optimal use of pasture land in order to use it optimally in the long term (to prevent overgrazing), or daily sub-optimal movements of cattle because of the yearly migration. The static, short-term approach that is basic to the models used for formulating these hypotheses could be inadequate for our analyses. The dynamic and long-term models seem more appropriate. Hence, we will try to search for a pattern in the exploitation strategy of herdsmen, a pattern that is in agreement with this conclusion.

SUBJECT OF STUDY

Fieldwork was carried out from October 4 through December 22, 1986, on cattle movements of a Fulani sedentary cattle owner in Burkina Faso. He had lived in the same area for 16 years, and was the head of an extended family comprising 18 people. In addition to 135 head of cattle, the family owns poultry, sheep, and goats, and also grows millet and other crops.

The daily herd management schedule was as follows: from 6 a.m. to 8 a.m. the herd was grazed near the homestead; around 8 a.m. the cattle were milked, after which they were led to fields removed from the settlements, and returned to the homestead around dusk, 6 p.m., to be milked again. During the last 2 weeks of the study, the cattle were moved to grazing fields again at night. Most often two herdsmen, sons of the family head, moved with the cattle. The herdsmen decided where to graze each day after consulting the head of the family. It should be stressed that the family has been sedentary in the area (their "home range") for a long period and knew it intimately.

STUDY AREA

The study area, situated approximately 18 km east of Ouagadougou, the capital of Burkina Faso, is characterized by tree savanna. Annual precipitation is 800–900 mm. The rainy season starts in April/May, the peak of the rains is in July/August, and in November the dry season begins.

Pastures visited during the study period were situated mainly in the lower parts of the region. These depression zones have a heterogeneous vegetation, and because of their location, water is sufficiently available, resulting in a vegetation which remains of good quality well into the dry season. Pastures at a higher elevation were also visited; in these pastures, the grass *Microchloa indica* was a major food source, but the cattle also consumed leaves and pods of *Acacia* spp. Several small hamlets can be found in the area, and over the years farmers have exploited many fields. During the last months of the year these fields are harvested, the major crops being millet and sorghum. After harvesting, much forage in the form of leaves and stalks remains on the fields, and offers a major food source to the cattle at this time of year.

METHOD

The quality of the herdsmen's decisions was studied by direct observation of the herd and its movements. The herd was followed between 8 a.m.–6 p.m. (referred to as daytime exploitation in this paper). During this period observations were collected on (1) travel times of different pastures, (2) foraging times in these pastures, (3) the sequence of visits to pastures, and (4) the vegetation types of the pastures. As a measure of intake, initially the number of bites per step was chosen. This parameter was measured every 3 minutes

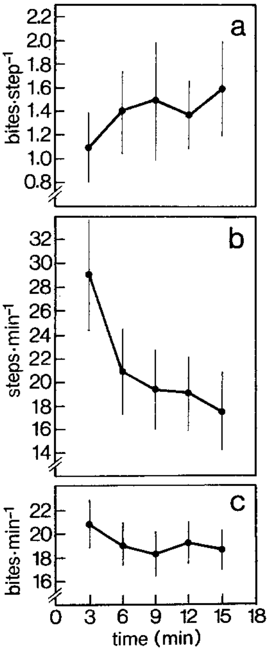


Fig. 3. (a) The number of bites per step, (b) steps per minute, and (c) bites per minute during the first 15 minutes of grazing by cattle in fields in Burkina Faso. The increase in the number of bites per step is determined by a decrease in the stepping rate.

during grazing and every 5 minutes during traveling. Each animal was chosen at random, i.e., focal animal sampling (Altmann, 1974) and was observed for 1 minute. Bite size was assumed to be constant.

Stubble field with harvest leftovers has a clear delimitation. This makes such fields easy to define as patches *sensu* the optimal foraging theory, in contrast to terrains with natural vegetation. Because of this, only the stubble fields were used in the analyses. It was considered possible that the simple models would not adequately describe the decisions of the cattle herdsmen. Interviews were conducted with the herdsmen and with the head of the family to determine other possible parameters to be taken into account in the analyses.

In the analyses, use was made of parametric tests (95% confidence intervals, linear regression according to the least-squares method, calculation of the significance of the regression through the product-momentum correlation coefficient (r), calculation of the proportion of the variance explained by the regression (R^2)), and of non-parametric tests (Spearman rank correlation coefficient (r_s)). All tests were two-tailed.

RESULTS

Exploitation at the Patch Level

An analysis of the data on the foraging behavior of the cattle during the first 15 minutes of foraging in fields shows a sharp drop in the numbers of steps. min^{-1} (Fig. 3b), which might indicate that the cattle are sampling the fields that have a heterogeneous distribution of forage because of harvesting by farmers. By walking around more during the initial phase of foraging in a new field, cattle might be seeking information about the heterogeneity in order to determine where best to graze. Because of the decreasing number of step. min^{-1} in the first period, the number of bites.step^{-1} (Fig. 3a) slightly increases in this period. The number of bites.min^{-1} (Fig. 3c) was apparently not affected by this sampling factor and is in agreement with the prediction of optimal foraging theory that grazing depresses the amount of food on offer and causes a reduction in the food intake of the cattle. In the remainder of this paper, bites.min^{-1} is therefore used as the measure of food intake.

Depletion of the quantity of food on offer should result in a decrease in food intake, so there should be a significant difference between the bite frequency in the first period of grazing and in the last one. In the analysis, the fields were divided into two groups. The first group comprised fields in which the cattle had grazed less than 20 minutes ("small fields"), the other group in which they had grazed longer than 20 minutes ("large fields"). The decrease in bite frequency in the "small" fields was 1.4 bites.min^{-1} (95% confidence interval ± 3.8 bites.min^{-1}). Accordingly, the first bite frequency of 19.2 bites.min^{-1} was not significantly different from the last frequency of 17.8 bites.min^{-1} in these "small" fields. In the "large" fields, the first bite frequency was 22.1.min^{-1} and the last 15.9.min^{-1}, which yields a significant decrease in bite frequency of 6.2 bites.min^{-1} (95% confidence interval ± 4.2 bites.min^{-1}). These findings suggest that depletion occurs in "large" fields.

The models of optimal foraging theory predict that, if patches have an identical yield curve for the forager and if these patches are exploited optimally, there is a relationship between travel time and foraging time (*Hypothesis 1*). The data in Fig. 4 show that the observations do not fall in line with this predicted relationship. From this it follows that *Hypothesis 1* is not valid for our study situation. It may be that the fields are not uniform or that optimal foraging theory models are not applicable here.

Heterogeneity of the fields can be drawn into the analysis by looking at the total food intake of the cattle in the different fields. If *Hypothesis 2* holds, then a field should be vacated if the intake per time unit in that field becomes equal to the intake rate in the whole exploitation area. The mean intake rate in the whole study area, i.e., not only the harvested fields but also the depression zones, the *Microchloa* vegetation, etc., during the entire study period was 10.2 bites.min^{-1}. This means that if in a particular field the mean intake rate cannot be higher than 10.2 bites.min^{-1}, this

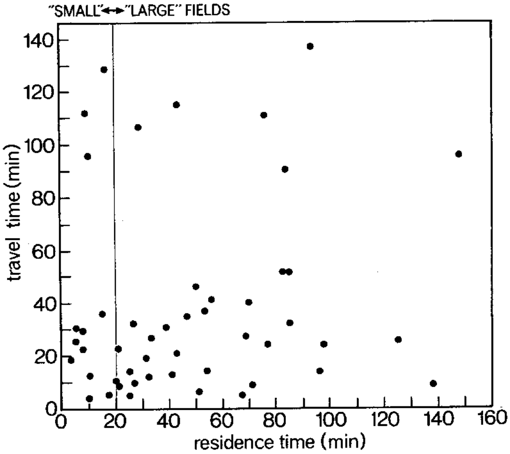


Fig. 4. The relation between travel time and residence time, i.e., foraging time, in all fields. A relationship between these two variables is not apparent (refuting *Hypothesis 1*).

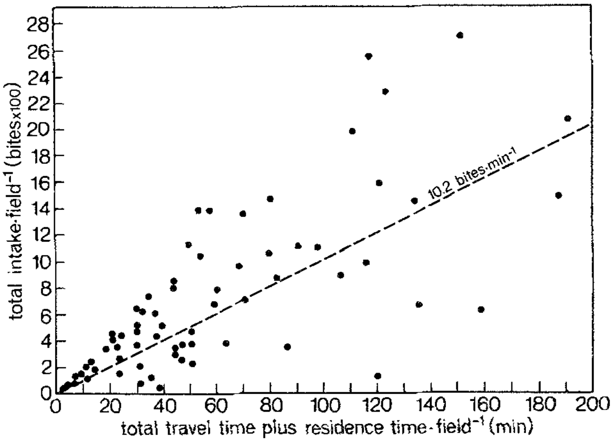


Fig. 5. The total intake in each field in relation to the total invested time for these fields; total invested time stands for residence time in the field plus travel time to reach the field. The average intake rate for the whole foraging area of the herd, i.e., fields, depression zones, *Microchloa* vegetation, etc., during the study period was 10.2 bites.min^{-1}. Note that most points fall above this mean intake rate, refuting *Hypothesis 2.*

field should not be visited with the herd. This is refuted by the data exhibited in Fig. 5. Moreover, the bite rate during the last period prior to departure of a field was often much higher (18.1 bites.min^{-1} with 95% confidence interval of 1.7) than would be predicted (10.2 bites.min^{-1}) by *Hypothesis 2.* This means either that *Hypothesis 2,* the marginal value theorem, is not adequate to explain the exploitation by herdsmen and cattle in this study, or that the subjects of the study were not behaving optimally.

Exploitation of Fields for a 1-Day Period

During the first part of the morning and the last part of the afternoon, herdsmen and cattle traveled relatively long distances (Fig. 6). Cumulative food intake, as measured by the number of bites, increased linearly with grazing time (Figs. 6 and 7), and there was no indication of satiation of the cattle during the day (Fig. 7). Some days showed a higher total cumulative food intake than others, (Fig. 8b), apparently caused by a shorter total travel time, as there is a negative correlation between total daily travel time and total daily food intake ($n = 12$, $r = -0.728$, $P < 0.02$, $R^2 = 53\%$). Some compensation for long travel times occurred, as there is a position correlation between total daily travel time and total food intake during traveling itself

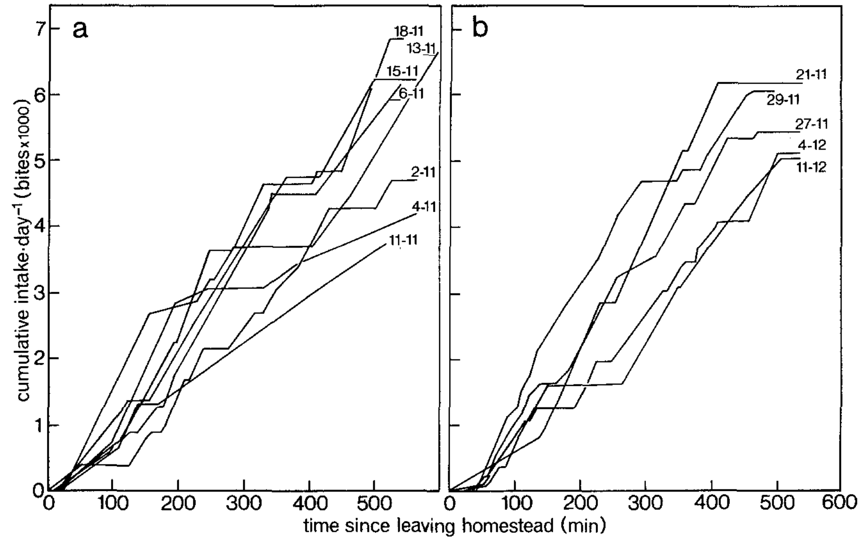


Fig. 6. Cumulative intake of the cattle during different days plotted against time since leaving the homestead in the morning. The horizontal lines represent traveling without foraging. The numbers refer to days and months.

(Fig. 8; $n = 12, r = +0.767, P < 0.01, R^2 = 59\%$). However, compensation took place only after a certain minimum amount of expended travel time (Fig. 8a). Thus, total daily travel time had a large influence on the total food intake of the cattle and can be viewed as a cost. Figure 9 shows what, in part, determined total daily travel time. Daily travel time diminished during the study period(Fig. 9a; $n = 12, r = -0.768, P < 0.01, R^2 = 60\%$) and daily food intake appeared to increase (Fig. 9b; $n = 12, r_s = 0.734, P < 0.02$). The most likely explanation for these observations is that, as the harvest progressed, an increasing number of stubble fields became available to the cattle (Fig. 9c; $n = 12, r = 0.936, P < 0.01, R^2 = 88\%$).

DISCUSSION

The theoretical models from optimal foraging theory that were used to analyze the above observations apply to situations of food exploitation at the level of a single patch in relation to other patches, where the exploiters are assumed to operate within a short-term time-frame. The results obtained in Burkina Faso do not fit into these models. However, the analysis at a higher level of integration, whole day, yields some useful correlations. This suggests that the herdsmen are able to plan which fields they intend to visit with their cattle, and that, accordingly, they make decisions at the

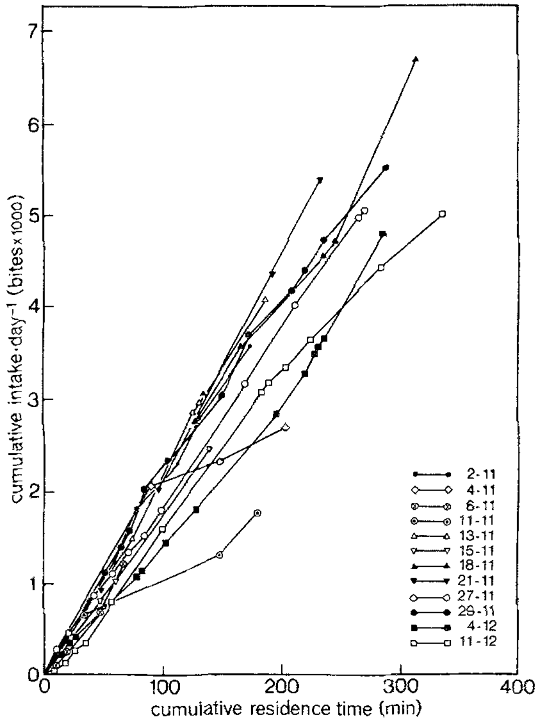


Fig. 7. Cumulative intake of the cattle during different days plotted against the cumulative foraging time on stubble fields during those days. There is no sign of satiation of the cattle. The numbers refer to days and months.

level of, at least, a whole day. This agrees with information obtained in the interviews: the herdsmen felt that they knew their area (home range) well, and they discussed which fields could be used for grazing with other herdsmen and farmers. It also appears that they made a rough itinerary of their daily travel and decided beforehand which fields would be visited and which ones would not.

Because of the sedentary life of these cattle owners, cattle depart from a fixed point in space to which they have to return at the end of day to be milked again. This pattern is instrumental in setting an upper limit to the total daily food intake, as the act of milking is more important than intake maximization. Indeed, the definition of currency to be maximized in the models is herd production. i.e., milk and calves, while the cattle's food intake is only a derived factor to be maximized. Decisions taken by the herdsmen at the beginning of the day, when the herd leaves the homestead, or those taken during a later stage in the day, have their repercussions on sub-

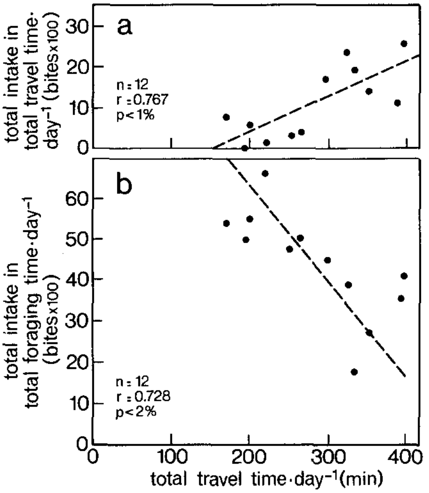


Fig. 8. (a) The total intake of the cattle while foraging, and (b) the total intake while traveling in relation to the travel time during days in the study period. (a) exhibits a significant positive correlation, and (b) a significant negative correlation.

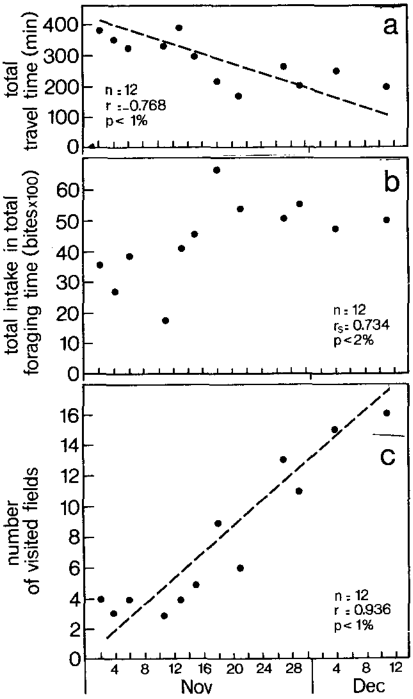
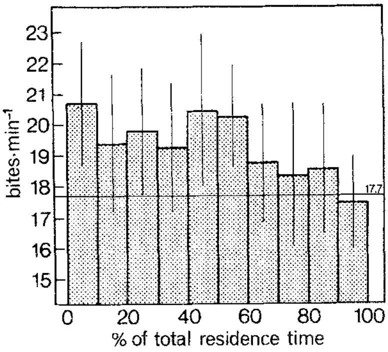


Fig. 9. (a) Travel time diminished, and (b) the total daily intake increased as a consequence of (c) more fields becoming available to the cattle as the harvest progressed during the study period. Note that, as apparently the total intake did not increase linearly over the study period ($r = 0.389$, N.S.), a Spearman-rank test was used in (b).

Fig. 10. The cattle's intake pattern over time in the "large" fields ($n = 22$) (stippled bars; vertical lines represent 95% confidence intervals; see text for details). The horizontal line identifies the mean total intake per total foraging time in the whole foraging area during the whole study period. Fields are vacated at the moment that the intake rate drops below the average rate which can be reached in the whole area (see *Hypothesis 3*).



sequent decisions and on the remainder of the route. From the interviews, it is clear that herdsmen are able to estimate travel times between different fields and it appears that daily total food intake in weighed against daily total travel time: the first is to be maximized and the second to be minimized. This implies that the separate travel times between fields are not viewed as being as important as the total travel time. The models of optimal foraging theory, however, view travel times for each field separately in relation to the food intake of those individual fields. We think that the discrepancy between the optimal foraging theory models and the actual strategy of the herdsmen is caused by this difference in outlook. An optimal strategy adopted by the herdsmen in which total travel time is minimized during the day but in which total intake during foraging is maximized, leads to the formulation of a new hypothesis.

Hypothesis 3. Cattle have to be moved from a field when the intake rate, i.e., intake per unit foraging time, of these cattle falls below the mean intake rate realized in the whole area of exploitation.

It should be stressed that *Hypothesis 3* is a derivative of *Hypothesis 2,* as their new hypothesis travel time is not used in calculating the optimal residence time in field. To test this new hypothesis, the data of the large fields were re-analyzed (as the small fields did not show a significant depression in intake rate these were not included in the analysis). Because we are now interested in exploitation in 1 day, the data of all fields visited on a particular day are taken together and averaged: total residence time in a field was set at 100% and divided into ten classes of 10% of the residence time each, and the mean bite rate was calculated for each class. The pattern this yields is presented in Fig. 10. The mean total intake rate while foraging for the whole study period was 17.7 bites:min^{-1} in the whole foraging area (again

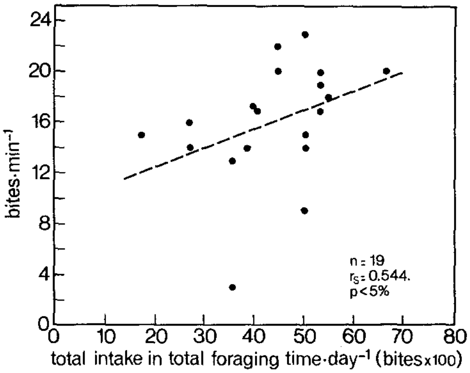


Fig. 11. The bite frequencies during the last 10% time of visits to the "large" fields plotted against total intake during foraging time on those days. The herdsmen apparently have an expectation about the total intake to be realized at the end of the day when they move through the terrain (see *Hypothesis 4*).

including depression zones, *Microchloa* vegetation, etc.). Hypothesis 3 appears to be confirmed. Figure 10 shows that cattle were moved from the large fields when the intake rate dropped to below this 17.7 bites:min^{-1} mean level and the mean intake rate in all other 10% classes was above this level.

As was exhibited in Figure 8 and 9, the total intake per day was different. If herdsmen adopted a strategy for 1 whole day, then their decisions should be dependent on the expected total intake to be reached at the end of the day. This can be shown by testing a fourth hypothesis.

Hypothesis 4. During days with a higher realized total food intake at the end of the day, fields must have been left at an earlier stage of exploitation (at a higher intake rate level) than during days with a longer total realized food intake.

In Fig. 11, the mean bite rates during the last 10% of the total duration of visits to the large fields is plotted against the total daily food intake for the days in which these visits were made. This scatter diagram shows that on days in which the total daily food intake was high, cattle were moved from the fields when the bite rate was higher than on days in which the total daily food intake was low ($n = 19$, $r_s = 0.544$, $P < 0.05$). This is in accordance with *Hypothesis 4,* and suggests that the herdsmen had an expectation about the daily total food intake which could be reached on each day, and used this expectation in deciding when to move their cattle from a field. In other words, if the intake rate of the cattle in one field dropped to below the expected mean level to be reached that day, they moved their cattle. This expectation can be different each day, depending on, for example, the availability of harvested fields.

The higher total intake during the second half of the research period, (i.e., after November 15; see Fig. 9) cannot be explained solely by a higher grazing efficiency of the stubble fields during that period. In the first half of the study, this efficiency amounted to 16.3 bites:min^{-1}, and in the second half it was 17:8. In the second half of the study, daily total travel time was clearly shorter than in the first half (217 and 348 minutes, respectively). It is likely that a shorter total travel time and more time to spare for grazing are just as important to attain a higher total intake as is an increased grazing efficiency.

These results appear to confirm the idea that travel time is to be viewed as an independent factor in the daily decision strategy, independent of both foraging time and total intake. This suggests that the travel time to a particular field should not be compared with the yield of that particular field (patch), as assumed in the marginal value theorem of Charnov (1976). The decision-making strategy of sedentary herdsmen in Burkina Faso can be understood if one assumes that daily travel time, daily foraging time, and daily total intake are weighed against one another, and that decisions are taken on the basis of a whole day, which results in planning at the level of (at least) a whole day. Hypothesis 3 appears to hold here, and offers a guideline for optimal exploitation of the large fields.

CONCLUSION

The optimal foraging models used to describe the optimal exploitation of a food resource are based on intake maximization and prescribe the optimal duration of foraging in a patch (field). We assumed that the West African herdsman uses the production of his herd (milk and calves) as the currency to be maximized. The cattle's food intake shows a direct link with their condition, and hence with the desired production. Thus, the food intake by cattle should be maximized within normal environmental conditions. Food intake is the derived currency to be maximized if the herdsmen want to maximize their production.

From the case study in Burkina Faso, it becomes clear that the movement strategy of the herdsman is not to be viewed at the level of exploitation of each patch individually. The conclusion that total daily travel time is an independent cost factor contributes to the conclusion that the herdsmen's strategy is much more dynamic than ordinarily viewed by proponents of optimal foraging theory. The time frame of decisions to be taken by these sedentary herdmen encompasses at least the time between departure from the homestead and the subsequent return to it. It is likely that with other forms of husbandry, such as nomadism or transhumance, individuals employ different and longer time frames in which to optimize their decisions. Nonetheless, the sedentary herdsman optimized the food intake of his cattle within the limits dictated by the daily need to return his cattle to the homestead for milking.

Different optimal foraging models enable us to order our investigations and also provide a framework within which to gauge the quality of these herdsmen's decisions. However, a number of other constraints (not incorporated in these models), such as the necessity to move back to the homestead at the end of the day, the water requirements of the cattle, and the necessity to evade heat stress, determine their decisions. Also, political, cultural, and social constraints might play a role independent of the herdsmen's desire to maximize the intake of their cattle. It is through observing the actual behavior of these herdsmen and by comparing it to the different optimal foraging models that we may obtain an instrument to weigh the importance of these constraints. Through initially discussing the simple models, and later the more complex ones, we may be able to ask the right questions about the types and qualities of the herdsmen's decisions. The dynamic models which take into account factors other than "only" intake maximization (such as the vagaries of the climate, uncertainty, variance of the food resources, and long-term strategies) are most likely to best describe the actual strategies employed among traditional herdsmen to survive in a stochastic environment. We still have much data to collect, however, before we will be able to develop such models and test them.

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