Self-Regulating Systems in Populations of Animals

A new hypothesis illuminates aspects of animal behavior that have hitherto seemed unexplainable.

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I am going to try to explain a hypothesis which could provide a bridge between two biological realms (*1*). On one side is that part of the "Balance of Nature" concerned with regulating the numbers of animals, and on the other is the broad field of social behavior. The hypothesis may, I believe, throw a bright and perhaps important side-light on human behavior and population problems. I must emphasize, however, that it is still a hypothesis. It appears to be generally consistent with the facts, and it provides entirely new insight into many aspects of animal behavior that have hitherto been unexplainable; but because it involves long-term evolutionary processes it cannot be put to an immediate and comprehensive test by short-term experiments.

Human populations are of course increasing at compound interest practically all over the world. At the overall 2 percent annual rate of the last decade, they can be expected to double with each generation. In the perspective of evolutionary time such a situation must be extremely short-lived, and I am sure we are going to grow more and more anxious about the future of man until we are able to satisfy ourselves that the human population explosion is controllable, and can be contained.

Populations of animals, especially when they are living under primeval undisturbed conditions, characteristically show an altogether different state of affairs; and this was equally true of man in the former cultural periods of the stone age. These natural populations tend to preserve a continuing state of balance, usually fluctuating to some extent but essentially stable and regulated. The nature of the regulatory process has been the main focus of study and speculation by animal ecologists during the whole of my working life, and in fact considerably longer.

Charles Darwin (*2*) was the first to point out that though all animals have the capacity to increase their numbers, in fact they do not continuously do so. The "checks to increase" appeared to him to be of four kinds—namely, the amount of food available, which must give the extreme limit to which any species can increase; the effects of predation by other animals; the effects of physical factors such as climate; and finally, the inroads of disease. "In looking at Nature," he tells us in the *Origin of Species*, "it is most necessary . . . never to forget that every single organic being may be said to be striving to the utmost to increase in numbers." This intuitive assumption of a universal resurgent pressure from within held down by hostile forces from without has dominated the thinking of biologists on matters of population regulation, and on the nature of the struggle for existence, right down to the present day.

Setting all preconceptions aside, however, and returning to a detached assessment of the facts revealed by modern observation and experiment, it becomes almost immediately evident that a very large part of the regulation of numbers depends not on Darwin's hostile forces but on the initiative taken by the animals themselves; that is to say, to an important extent it is an intrinsic phenomenon.

Forty years ago Jespersen (*3*) showed, for example, that there is a close numerical agreement between the standing crop of planktonic organisms at the surface of the North Atlantic Ocean and the distribution density of the various deep-sea birds that depend on these organisms for food. Over the whole of this vast area the oceanic birds are dispersed in almost constant proportion to the local biomass of plankton, although the biomass itself varies from region to region by a factor of about 100; the actual crude correlation coefficient is 85 percent. This pro rata dispersion of the birds must in fact depend solely on their own intrinsic efforts and behavior. Even though the dispersion directly reflects the availability of food, the movements of the birds over the ocean are essentially voluntary and not imposed against their will by hostile or other outside forces.

Turning to the results of repeatable experiments with laboratory animals, it is a generally established principle that a population started up, perhaps from one parental pair, in some confined universe such as an aquarium or a cage, can be expected to grow to a predictable size, and thereafter to maintain itself at that ceiling for months or years as long as the experimenter keeps the conditions unchanged. This can readily be demonstrated with most common laboratory animals, including the insects *Drosophila* and *Tribolium*, the water-flea *Daphnia*, the guppy *Lebistes*, and also mice and rats. The ceiling population density stays constant in these experiments in the complete absence of predators or disease and equally without recourse to regulation by starvation, simply by the matching of recruitment and loss. For example, a set of particularly illuminating experiments by Silliman and Gutsell (*4*), lasting over 3 years, showed that when stable populations of guppies, kept in tanks, were cropped by removal of a proportion of the fish at regular intervals, the remainder responded by producing more young that survived, with the consequence that the losses were compensated. In the controls, on the other hand, where the stocks were left untouched, the guppies went on breeding all the time, but by cannibalism they consistently removed at birth the whole of the surplus produced. The regulating methods are different in different species; under appropriate circumstances in mice, to take another example, ovulation and reproduction can

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decline and even cease, as long as the ceiling density is maintained.

Here again, therefore, we are confronted by intrinsic mechanisms, in which none of Darwin's checks play any part, competent in themselves to regulate the population size within a given habitat.

The same principle shows up just as clearly in the familiar concept that a habitat has a certain carrying capacity, and that it is no good turning out more partridges or planting more trout than the available habitat can hold.

Population growth is essentially a density-dependent process; this means that it tends to proceed fastest when population densities are far below the ceiling level, to fall to zero as this level is approached, and to become negative, leading to an actual drop in numbers, if ever the ceiling is exceeded. The current hypothesis is that the adjustment of numbers in animals is a homeostatic process—that there is, in fact, an automatic self-righting balance between population density and resources.

I must turn briefly aside here to remind you that there are some environments which are so unstable or transitory that there is not time enough for colonizing animals to reach a ceiling density, and invoke their regulatory machinery, before the habitat becomes untenable again or is destroyed. Populations in these conditions are always in the pioneering stage, increasing freely just as long as conditions allow. Instability of this kind tends to appear around the fringes of the geographical range of all free-living organisms, and especially in desert and polar regions. It is also very common in agricultural land, because of the incessant disturbance of ploughing, seeding, spraying, harvesting, and rotating of crops. In these conditions the ecologist will often look in vain for evidences of homeostasis, among the violently fluctuating and completely uncontrollable populations typical of the animal pests of farms and plantations. Homeostasis can hardly be expected to cope unerringly with the ecological turmoil of cultivated land.

I return later to the actual machinery of homeostasis. For the present it can be accepted that more or less effective methods of regulating their own numbers have been evolved by most types of animals. If this is so, it seems logical to ask as the next question: What is it that decides the ceiling level?

Food Supply as a Limiting Factor

Darwin was undoubtedly right in concluding that food is the factor that normally puts an extreme limit on population density, and the dispersion of oceanic birds over the North Atlantic, which so closely reflects the dispersion of their food supply, is certain to prove a typical and representative case. Just the same, the link between food productivity and population density is very far from being self-evident. The relationship between them does not typically involve any signs of undernourishment; and starvation, when we observe it, tends to be a sporadic or accidental cause of mortality rather than a regular one.

Extremely important light is shed on this relationship between population density and food by our human experience of exploiting resources of the same kind. Fish, fur-bearing animals, and game are all notoriously subject to overexploitation at the hands of man, and present-day management of these renewable natural resources is based on the knowledge that there is a limit to the intensity of cropping that each stock can withstand. If we exceed this critical level, the stock will decline and the future annual crops will diminish. Exactly parallel principles apply to the exploitation of natural prairie pastures by domestic livestock: if overgrazing is permitted, fertility and future yields just as fatally decline.

In all these situations there is a tendency to overstep the safety margin while exploitation of the resource is still economically profitable. We have seen since World War II, for example, the decimation of stocks of the blue and the humpback whale in the southern oceans, under the impetus of an intense profit motive, which persisted long after it had become apparent to everyone in the industry that the cropping rate was unsupportably high. The only way to protect these economically valuable recurrent resources from destruction is to impose, by agreement or law, a man-made code of rules, defining closed seasons, catch limits, permitted types of gear, and so on, which restrict the exploitation rate sufficiently to prevent the catch from exceeding the critical level.

In its essentials, this is the same crucial situation that faces populations of animals in exploiting their resources of food. Indeed, without going any further one could predict that if the food supplies of animals were openly exposed to an unruly scramble, there could be no safeguard against their overexploitation either.

Conventional Behavior in Relation to Food

When I first saw the force of this deduction 10 years ago, I felt that the scales had fallen from my eyes. At once the vast edifice of conventional behavior among animals in relation to food began to take on a new meaning. A whole series of unconnected natural phenomena seemed to click smoothly into place.

First among these are the territorial systems of various birds (paralleled in many other organisms), where the claim to an individual piece of ground can evoke competition of an intensity unequaled on any other occasion in the life of the species concerned. It results, in the simplest cases, in a parceling out of the habitat into a mosaic of breeding and feeding lots. A territory has to be of a certain size, and individuals that are unsuccessful in obtaining one are often excluded completely from the habitat, and always prevented from breeding in it. Here is a system that might have been evolved for the exact purpose of imposing a ceiling density on the habitat, and for efficiently disposing of any surplus individuals that fail to establish themselves. Provided the territory size is adequate, it is obvious that the rate of exploitation of the food resources the habitat contains will automatically be prevented from exceeding the critical threshold.

There are other behavioral devices that appear, in the light of the food-resource hypothesis we are examining, equally purposive in leading to the same result—namely, that of limiting the permitted quota of participants in an artificial kind of way, and of off-loading all that are for the time being surplus to the carrying capacity of the ground. Many birds nest in colonies—especially, for example, the oceanic and aerial birds which cannot, in the nature of things, divide up the element in which they feed into static individual territories. In the colony the pairs compete just as long and keenly for one of the acceptable nest sites, which are in some instances closely packed together. By powerful tradition some of these species return year after year to old-established resorts, where the perimeter of the colony is closely drawn like an imaginary fence around the occupied sites. Once again there is not always room to accommodate all the contestants, and unsuccessful ones have to be relegated to a nonbreeding surplus or reserve, inhibited from sexual maturation because they have failed to obtain a site within the traditional zone and all other sites are taboo.

A third situation, exemplifying another, parallel device, is the pecking order or social hierarchy so typical of the higher animals that live in companies in which the individual members become mutually known. Animal behaviorists have studied the hierarchy in its various manifestations for more than 40 years, most commonly in relation to food. In general, the individuals of higher rank have a prior right to help themselves, and, in situations where there is not enough to go round, the ones at the bottom of the scale must stand aside and do without. In times of food shortage—for example, with big game animals—the result is that the dominant individuals come through in good shape while the subordinates actually die of starvation. The hierarchy therefore produces the same kind of result as a territorial system in that it admits a limited quota of individuals to share the food resources and excludes the extras. Like the other devices I have described, it can operate in exactly the same way with respect to reproduction. In fact, not only can the hierarchical system exclude individuals from breeding, it can equally inhibit their sexual development.

It must be quite clear already that the kind of competition we are considering, involving as it does the right to take food and the right to breed, is a matter of the highest importance to the individuals that engage in it. At its keenest level it becomes a matter of life and death. Yet, as is well known, the actual contest between individuals for real property or personal status is almost always strictly conventionalized. Fighting and bloodshed are superseded by mere threats of violence, and threats in their turn are sublimated into displays of magnificence and virtuosity. This is the world of bluff and status symbols. What takes place, in other words, is a contest for conventional prizes conducted under conventional rules. But the contest itself is no fantasy, for the losers can forfeit the chance of posterity and the right to survive.

Conventionalized Rivalry and Society

It is at this point that the hypothesis provides its most unexpected and striking insight, by showing that the conventionalization of rivalry and the foundation of society are one and the same thing. Hitherto it has never been possible to give a scientific definition of the terms *social* and *society*, still less a functional explanation. The emphasis has always been on the rather vague element of companionship and brotherhood. Animals have in the main been regarded as social whenever they were gregarious. Now we can view the social phenomenon in a new light. According to the hypothesis the society is no more and no less than the organization necessary for the staging of conventional competition. At once it assumes a crisp definition: a society is an organization of individuals that is capable of providing conventional competition among its members.

Such a novel interpretation of something that involves us all so intimately is almost certain to be viewed at first sight a bit skeptically; but in fact one needs no prompting in our competitive world to see that human society is impregnated with rivalry. The sentiments of brotherhood are warm and reassuring, and in identifying society primarily with these we appear to have been unconsciously shutting our eyes to the inseparable rough-and-tumble of status seeking and social discrimination that are never very far to seek below the surface, bringing enviable rewards to the successful and pitiful distress to those who lose. If this interpretation is right, conventional competition is an inseparable part of the substance of human society, at the parochial, national, and international level. To direct it into sophisticated and acceptable channels is no doubt one of the great motives of civilized behavior; but it would be idle to imagine that we could eliminate it.

A corollary of the hypothesis that deserves mention is the extension of sociality that it implies, to animals of almost every kind whether they associate in flocks or seek instead a more solitary way of life. There is no particular difficulty of course in seeing, for example, cats and dogs as social mammals individually recognizing the local and personal rights of acquaintances and strangers and inspired by obviously conventional codes of rivalry when they meet. In a different setting, the territory-holding birds that join in the chorus of the spring dawn are acting together in social concert, expressing their mutual rivalry by a conventional display of exalted sophistication and beauty. Even at the other extreme, when animals flock into compact and obviously social herds and schools, each individual can sometimes be seen to maintain a strict individual distance from its companions.

Social Organization and Feedback

We can conveniently return now to the subject of homeostasis, in order to see how it works in population control. Homeostatic systems come within the general purview of cybernetics; in fact, they have long been recognized in the physiology of living organisms. A simple model can be found in any thermostatic system, in which there must of course be units capable of supplying or withdrawing heat whenever the system departs from its standard temperature and readjustment is necessary. But one also needs an indicator device to detect how far the system has deviated and in which direction. It is the feedback of this information that activates the heating or cooling units.

Feedback is an indispensable element of homeostatic systems. There seems no reason to doubt that, in the control of population density, it can be effectively provided simply by the intensity of conventional competition. Social rivalry is inherently density-dependent: the more competitors there are seeking a limited number of rewards, the keener will be the contest. The impact of stress on the individuals concerned, arising from conventional competition and acting through the pituitary-adrenal system, is already fully established, and it can profoundly influence their responses, both physiological and behavioral.

One could predict on theoretical grounds that feedback would be specially important whenever a major change in population density has to take place, upsetting the existing balance between demand and resources. This must occur particularly in the breeding season and at times of seasonal migrations. Keeping this in mind, we can obtain what we need in the way of background information by examining the relatively long-lived vertebrates, including most kinds of birds and mammals, whose individual members live long enough to constitute a standing population all the year round. The hypothesis of course implies that reproduction, as one of the principal parameters of population, will be subject to control—adjusted in magnitude, in fact, to meet whatever addition is currently required to build up the population and make good the losses of the preceding year. *Recruitment* is a term best used only to mean intake of new breeding adults into the population, and in that sense, of course, the raw birth rate may not be the sole and immediate factor that determines it. The newborn young have got to survive adolescence before they can become recruits to the breeding stock; and even after they attain puberty, social pressures may exclude them from reproducing until they attain a sufficiently high rank in the hierarchy. Indeed, there is evidence in a few species that, under sufficient stress, adults which have bred in previous years can be forced to stand aside.

There are, in fact, two largely distinct methods of regulating reproductive output, both of which have been widely adopted in the animal kingdom. One is to limit the number of adults that are permitted to breed, and this is of course a conspicuous result of adopting a territorial system, or any other system in which the number of permissible breeding sites is restricted. The other is to influence the number of young that each breeding pair is conditioned to produce. The two methods can easily be combined.

What we are dealing with here is a part of the machinery for adjusting population density. What we are trying to get at, however, is the social feedback mechanism behind it, by which the appropriate responses are elicited from potential breeders.

Birds generally provide us with the best examples, because their size, abundance, and diurnal habits render them the most observable and familiar of the higher animals. It is particularly easy to see in birds that social competition is keenest just before and during the breeding season, regardless of the type of breeding dispersion any given species happens to adopt. Individuals may compete for and defend territories or nest sites, or in rarer cases they may engage in tournaments in an arena or on a strutting ground; and they may join in a vocal chorus especially concentrated about the conventional hours of dawn and dusk, make mass visits to colony sites, join in massed flights, and share in other forms of communal displays. Some of these activities are more obviously competitive than others, but all appear to be alike in their capacity to reveal to each individual the concentration or density level of the population within its own immediate area.

Communal Male Displays

Some of these activities, like territorial defense, singing, and the arena displays, tend to be the exclusive concern of the males. It has never been possible hitherto to give a satisfactory functional explanation of the kind of communal male displays typified by the arena dances of some of the South American hummingbirds and manakins, and by the dawn strutting of prairie chickens and sharp-tailed grouse. The sites they use are generally traditional, each serving as a communal center and drawing the competitors from a more or less wide surrounding terrain. On many days during the long season of activity the same assembly of males may engage in vigorous interplay and mutual hostility, holding tense dramatic postures for an hour or more at a stretch without a moment's relaxation, although there is no female anywhere in sight at the time. The local females do of course come at least once to be fertilized; but the performance makes such demands on the time and energy of the males that it seems perfectly reasonable to assume that this is the reason why they play no part in nesting and raising a family. The duty they perform is presumably important, but it is simply not credible to attribute it primarily to courting the females. To anyone looking for a population feedback device, on the other hand, interpretation would present no difficulty: he would presume that the males are being conditioned or stressed by their ritual exertions. In some of the arena species some of the males are known to be totally excluded from sexual intercourse; but it would seem that the feedback mechanism could produce its full effect only if it succeeded in limiting the number of females fertilized to an appropriate quota, after which the males refused service to any still remaining unfertilized. I hope research may at a not-too-distant date show us whether or not such refusal really takes place.

The conclusion that much of the social display associated with the breeding season consists of males competing with males makes necessary a reappraisal of Darwinian sexual selection. Whether the special organs developed for display are confined to the males, as in the examples we have just considered, or are found in both sexes, as for instance in most of the colony-nesting birds, there is a strong indication that they are first and foremost status symbols, used in conventional competition, and that the selective process by which they have been evolved is social rather than sexual. This would account for the hitherto puzzling fact that, although in the mature bullfrog and cicada the loud sound is produced by the males, in both cases it is the males that are provided with extra-large eardrums. There does not seem much room for doubt about who is displaying to whom.

Communal displays are familiar also in the context of bird migration, especially in the massing and maneuvering of flocks before the exodus begins. A comparable buildup of social excitement precedes the migratory flight of locusts. Indeed, what I have elsewhere defined as *epideictic* phenomena—displays, or special occasions, which allow all the individuals taking part to sense or become conditioned by population pressure—appear to be very common and widespread in the animal kingdom. They occur especially at the times predicted, when feedback is required in anticipation of a change in population density. The singing of birds, the trilling of katydids, crickets, and frogs, the underwater sounds of fish, and the flashing of fireflies all appear to perform this epideictic function. In cases where, as we have just seen, epideictic behavior is confined in the breeding season to the male sex, the presumption is that the whole process of controlling the breeding density and the reproductive quota is relegated to the males. Outside the breeding season, when the individuals are no longer united in pairs and are all effectively neuter in sex, all participate alike in epideictic displays—in flighting at sundown, like ducks; in demonstrating at huge communal roosts at dusk, like starlings, grackles, and crows; or in forming premigratory swarms, like swallows. The assumption which the hypothesis suggests, that the largest sector of all social behavior must have this fundamentally epideictic or feedback function, gives a key to understanding a vast agglomeration of observed animal behavior that has hitherto been dubiously interpreted or has seemed altogether meaningless.

Maintaining Population Balance

Having outlined the way in which social organization appears to serve in supplying feedback, I propose to look again at the machinery for making adjustments to the population balance. In territorial birds, variations in the average size of territories from place to place and year to year can be shown to alter the breeding density and probably also the proportion of adults actually participating in reproduction. In various mammals the proportion of the females made pregnant, the number and size of litters, the survival of the young and the age at which they mature may all be influenced by social stress. Wherever parental care of the young has been evolved in the animal kingdom, the possibility exists that maternal behavior and solicitude can be affected in the same way; and the commonly observed variations in survival rates of the newborn could, in that case, have a substantial functional component and play a significant part in regulating the reproductive output. This would, among other things, explain away the enigma of cannibalism of the young, which we noticed earlier in the guppies and which occurs sporadically all through the higher animals. Infanticide played a conspicuous part in reducing the effective birth rate of many of the primitive human peoples that survived into modern times. Not infrequently it took the form of abandoning the child for what appeared to be commendable reasons, without involving an act of violence.

Reproduction is of course only one of the parameters involved in keeping the balance between income and loss in populations. The homeostatic machinery can go to work on the other side of the balance also, by influencing survival. Already, in considering the recruitment of adults, we have taken note of the way this can be affected by juvenile mortality, some of which is intrinsic in origin and capable of being promoted by social pressures. Conventional competition often leads to the exclusion of surplus individuals from any further right to share the resources of the habitat, and this in turn compels them to emigrate. Research conducted at Aberdeen in the last 8 years has shown how important a factor forced expulsion is in regulating the numbers of the Scottish red grouse. Every breeding season so far has produced a population surplus, and it is the aggressive behavior of the dominant males which succeeds in driving the supernumeraries away. In this case the outcasts do not go far; they get picked up by predators or they mope and die because they are cut off from their proper food. Deaths from predation and disease can in fact be substantially "assisted" under social stress.

On the income side, therefore, both reproductive input and the acquisition of recruits by immigration appear to be subject to social regulation; and on the loss side, emigration and what can be described as socially induced mortality can be similarly affected. Once more it appears that it is only the inroads of Darwin's "checks to increase," the agents once held to be totally responsible for population regulation, which are in fact uncontrollable and have to be balanced out by manipulation of the other four components.

Attention must be drawn to the intimate way in which physiology and behavior are entwined in providing the regulatory machinery. It seems certain that the feedback of social stimulation acts on the individual through his endocrine system, and in the case of the vertebrates, as I have said, this particularly involves the pituitary and adrenal cortex or its equivalent. Sometimes the individual's response is primarily a physiological one—for example, the inhibition of spermatogenesis or the acceleration of growth; sometimes it is purely behavioral, as in the urge to return to the breeding site, the development of aggressiveness, or the demand for territory of a given size. But often there is a combination of the two—that is to say, a psychosomatic response, as when, for instance, the assumption of breeding colors is coupled with the urge to display.

Sources of Controversy

There is no need for me to emphasize that the hypothesis is controversial. But almost all of it is based on well-established fact, so that the controversy can relate solely to matters of interpretation. Examples have been given here which show the ability of the hypothesis to offer new and satisfying interpretations of matters of fact where none could be suggested before. Some of these matters are of wide importance, like the basic function of social behavior; some are matters of everyday experience, like why birds sing at dawn. Very seldom indeed does the hypothesis contradict well-founded accepted principles. What, then, are the sources of controversy?

These are really three in number, all of them important. The first is that the concept is very wide-ranging and comprehensive; this means that it cannot be simply proved or disproved by performing a decisive experiment. There are of course dubious points where critical tests can be made, and research is proceeding, at Aberdeen among many other places, toward this end. Relevant results are constantly emerging, and at many points the hypothesis has been solidified and strengthened since it was first formulated. On the other hand, there has been no cause yet to retract anything.

The second source of controversy is that the hypothesis invokes a type of natural selection which is unfamiliar to zoologists generally. Social grouping is essentially a localizing phenomenon, and an animal species is normally made up of countless local populations all perpetuating themselves on their native soil, exactly as happens in underdeveloped and primitive communities of man. Social customs and adaptations vary from one local group to another, and the hypothesis requires that natural selection should take place between these groups, promoting those with more effective social organizations while the less effective ones go under. It is necessary, in other words, to postulate that social organizations are capable of progressive evolution and perfection as entities in their own right. The detailed arguments (*5*) are too complex to be presented here, but I can point out that intergroup selection is far from being a new concept: It has been widely accepted for more than 20 years by geneticists. It is almost impossible to demonstrate it experimentally because we have to deal with something closely corresponding to the rise and fall of nations in history, rather than with success or failure of single genes over a few generations; it is therefore the time scale that prevents direct experiment. Even the comparatively rapid process of natural selection acting among individuals has been notoriously difficult to demonstrate in nature.

The third objection is, I think, by far the most interesting. It is simply that the hypothesis does not apply to ourselves. No built-in mechanisms appear to curb our own population growth, or adjust our numbers to our resources. If they did so, everything I have said would be evident to every educated child, and I should not be surveying it here. How is this paradox to be explained?

The answer, it seems clear, is that these mechanisms did exist in primitive man and have been lost, almost within historic times. Man in the paleolithic stage, living as a hunter and gatherer, remained in balance with his natural resources just as other animals do under natural conditions. Generation after generation, his numbers underwent little or no change. Population increase was prevented not by physiological control mechanisms of the kind found in many other mammals but only by behavioral ones, taking the form of traditional customs and taboos. All the stone age tribes that survived into modern times diminished their effective birth rate by at least one of three ritual practices—infanticide, abortion, and abstention from intercourse. In a few cases, fertility was apparently impaired by surgery during the initiation ceremonies. In many cases, marriage was long deferred. Mortality of those of more advanced age was often raised through cannibalism, tribal fighting, and human sacrifice.

Gradually, with the spread of the agricultural revolution, which tended to concentrate the population at high densities on fertile soils and led by degrees to the rise of the town, the craftsman, and the merchant, the old customs and taboos must have been forsaken. The means of population control would have been inherited originally from man's subhuman ancestors, and among stone age peoples their real function was probably not even dimly discerned except perhaps by a few individuals of exceptional brilliance and insight. The continually expanding horizons and skills of modern man rendered intrinsic limitation of numbers unnecessary, and for 5,000 or 10,000 years the advanced peoples of the Western world and Asia have increased without appearing to harm the world about them or endanger its productivity. But the underlying principles are the same as they have always been. It becomes obvious at last that we are getting very near the global carrying capacity of our habitat, and that we ought swiftly to impose some new, effective, homeostatic regime before we overwhelm it, and the ax of group selection falls.

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The Nature of Matter: Purposes of High Energy Physics

This group of articles consists of four chapters from a book published in January by Brookhaven National Laboratory. The introduction to the group was written by Luke C. L. Yuan, editor of the volume and a senior physicist at Brookhaven National Laboratory, Upton, New York. H. A. Bethe is professor of physics at Cornell University, Ithaca, New York. Victor F. Weisskopf is director general of CERN (European Organization for Nuclear Research), Geneva. Julian Schwinger is professor of physics at Harvard University, Cambridge, Massachusetts. G. C. Wick is a senior physicist at Brookhaven National Laboratory.

Introduction

This is a résumé of a recently published book in which 30 leading theoretical physicists present a remarkably unanimous plea for support for high energy physics and for the construction of much more powerful particle accelerators. This volume, entitled *Nature of Matter—Purposes of High Energy Physics* includes articles by H. A. Bethe, T. D. Lee, J. S. Schwinger, V. F. Weisskopf, C. N. Yang, and other prominent theorists, both American and foreign. It is intended to present to the general public as well as to the scientific community a collection of diversified views embracing many aspects of high energy physics (often referred to as particle or subnuclear physics) and aiming for a better understanding of the fundamental importance of the subject and its implications in all branches of science.

The main point of agreement among these scientists is that more extensive investigations into a considerably higher energy domain than presently available must necessarily be pursued in order to uncover the basic laws of nature. A higher energy accelerator, higher by a factor of the order of 10 to 30 than the 33-billion electron volt Alternating Gradient Synchrotron at Brookhaven, will be needed for the pursuit of these investigations.

J. Robert Oppenheimer, director of the Institute for Advanced Study at Princeton, wrote the foreword of the book, providing a general account of the views presented. Oppenheimer states: "When the first particle accelerators were designed and built, more than three decades ago, they had a clear purpose. Apart from the quanta of light and gravitation, the only particles known to physicists were electrons and protons, and atomic theory explained their interactions. The accelerators were built to study nuclear reactions, to enable protons and other nuclei to approach closely to nuclear targets, despite the fact that both projectile and target were positively charged, and thus repel one another. This program led to the rapid development of nuclear physics. . . . Today, physicists have given serious thought and study to the very large enterprise of building an accelerator in the range of several hundred to one thousand billion volts to explore structure in the range below 10^{-15} cm, in