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GENETIC CONSERVATION: OUR EVOLUTIONARY RESPONSIBILITY

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ABSTRACT

The conservation of the crop varieties of traditional agriculture in the centers of genetic diversity is essential to provide genetic resources for plant improvement. These resources are acutely threatened by rapid agricultural development which is essential for the welfare of millions. Methodologies for genetic conservation have been worked out which are both effective and economical. Urgent action is needed to collect and preserve irreplaceable genetic resources.

Wild species, increasingly endangered by loss of habitats, will depend on organized protection for their survival. On a long term basis this is feasible only within natural communities in a state of continuing evolution, hence there is an urgent need for exploration and clarification of the genetic principles of conservation. Gene pools of wild species are increasingly needed for various uses, from old and new industries to recreation. But the possibility of a virtual end to the evolution of species of no direct use to man raises questions of responsibility and ethics.

T*HE time scaleof concern:* The widespread concern with the fate of the natural and cultural heritage now exposed to a hurricane of change is finding expression in the concept of *the national estate.* This concept denotes landscapes, sites or objects of social, cultural, historical, aesthetic, scientific or economic significance which are or should be preserved. By analogy, one can recognize a *genetic estate* which comprises the biological heritage, the genetic endowment of organisms now living. One can view it as four distinctive groups, each with specific problems and methodological approaches—man, micro-organisms, domesticated plants and animals, and wild plants and animals, i.e., wild species of little or no ostensible economic significance.

The genetic estate is a more sophisticated concept than the national estate. The latter is conservative and static, whereas the genetic estate is forward-looking and dynamic: its essence is its evolutionary potential. Accordingly it has a more meaningful time scale. Since it deals with processes it has at least a national time dimension. This may be relatively brief, as for the breeding of crops or livestock, or it may be infinite, as for the evolution of species in natural communities. Thus genetic conservation has a *time scale of concern*, which extends from a day or a year when there is no need (or plan) for conservation, to infinity (Table 1). But the time scale of concern must not be confused with the *time for action*, which clearly is *now*. I shall confine this discussion to domesticated plants and to wild plants and animals, partly because I am familiar with them, partly because they are sufficient for establishing principles of genetic conservation.

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TABLE 1

The time scale of concern

	Period	Operator	Objective	Time scale
Wild-life	to 8,000 BC	hunter-gatherer	next meal	1 day
Domesticated plants	to 1850 AD	"primitive" or "traditional" peasant farmer	the next crop	1 year
	from 1850	plant breeder	the next variety	10 years
	from 1900	crop evolutionist	to broaden the genetic base	100 years
Wildlife	today	genetical conservationist	dynamic wildlife conservation	10,000 years +
		politician	current public interest	next election

Let us briefly consider the time scale of concern for these two groups. Neither our pre-agricultural ancestor, nor the peasant farmer who succeeded him had cause for concern beyond the next meal or the next crop, the former because he used a pool of great species diversity, the latter a pool of self-renewing intraspecific diversity. This came to an end with the advent of scientific selection. Today's concern is with preserving and broadening the genetic base. The time perspective for gene pool conservation might be the next 50 or 100 years—which is merely an acknowledgment of the unparalleled technological transience of our age; we cannot foresee even what kinds of crops will be used at that time.

For wildlife conservation the position is altogether different. Concern for its preservation is new, a consequence of our destructive age. Nature conservation is fighting for reserves and for legal recognition. The sights often are set for the short term, although perpetuity is its ultimate objective. Genetic wildlife conservation makes sense only in terms of an evolutionary time scale. Its sights must reach into the distant future.

In this context genetics has social responsibilities in two directions: first, to collaborate in planning the biological system of conservation so as to establish the highest possible evolutionary potential; second, to help in establishing an evolutionary ethic, as part of our social ethics, which will make it acceptable and indeed inevitable for civilized man to regard the continuing existence of other species as an integral part of his own existence. This demands continuing evolution.

I shall now attempt to give some substance to the points I have introduced.

DOMESTICATED PLANTS

Crop evolution and adaptation: The impact of genetics on society dates back to the origins of agriculture. Around 8,000 B.C. our ingenious ancestors discovered that the variations which transformed wild plants into crops were passed through the seed to the next generation. Cultivation led to settled civilization and thus to the origins of our society. The first agricultural revolution was the greatest contribution of genetics to society during the first 10,000 years.

From the areas where plants and animals were domesticated, they fanned out diversifying in the different environments and cultures to which they migrated, and in which they continued to evolve and diversify under the impact of changing technological, economic and cultural conditions. When the application of science to agriculture, and especially the advent of scientific plant breeding, ushered in the second agricultural revolution, modern varieties, bred for high production and uniformity, absorbed only a small proportion of the ancient stores of variation. Today the same, or closely related, varieties are grown in many parts of the world. Even in the less developed countries uniform modern cultivars are rapidly replacing the traditional, or "primitive" varieties which were still in general use even 25 years ago. The "green revolution" has greatly intensified this process in some Asian countries. No doubt the dramatic improvement of food production has saved mankind from extensive starvation, at least for the time being; but it also has deprived the world of valuable genetic resources, and, as a recent survey shows, much of what remains is now acutely threatened (FRANKEL 1973). Yet the world needs these genetic resources more than ever before. The extent and rapidity of technological and social change make demands for genetic adaptation which are as diverse as they are unpredictable. They are intensified by the population explosion and the agricultural revolution in vast areas previously scarcely touched by modern developments. The genetic resources now available are, foreseeably, the only ones we shall have available at least for the next few decades. But even if there is a chance that new methods of genetic engineering become widely applicable in the near future, at this stage the preservation of what we know and have seems a responsible measure of evolutionary insurance.

Crop genetic resources—definitions and stocktaking: I have already emphasized that in the advanced varieties of modern agriculture the genetic base is greatly narrowed by comparison with the primitive varieties from which they are descended. The great genetic diversity to be found in the traditional stocks of peasant agriculture was first emphasized by N. I. VAVILOV half a century ago; and it is thanks to him and his colleagues that we came to recognize "centres of genetic diversity," situated in Asia, Latin America and Africa, where domesticated plants originated (or migrated) and diversified, and where to this day many of the presumed progenitors and other wild or weed relatives of crop species can be found. Wild and primitive gene pools, together with induced mutations, constitute the genetic resources available for the adaptation of present-day cultivars, or for initiating new and potentially valuable pathways of crop evolution, such as the restructuring of existing alloploids, or the construction of new alloploids such as Triticale.

The left column in Figure 1 lists the three kinds of genetic resources and the genetic contributions which can be derived from them. All three may contribute *specific alleles*, and this has been the major contribution sought to date. Even

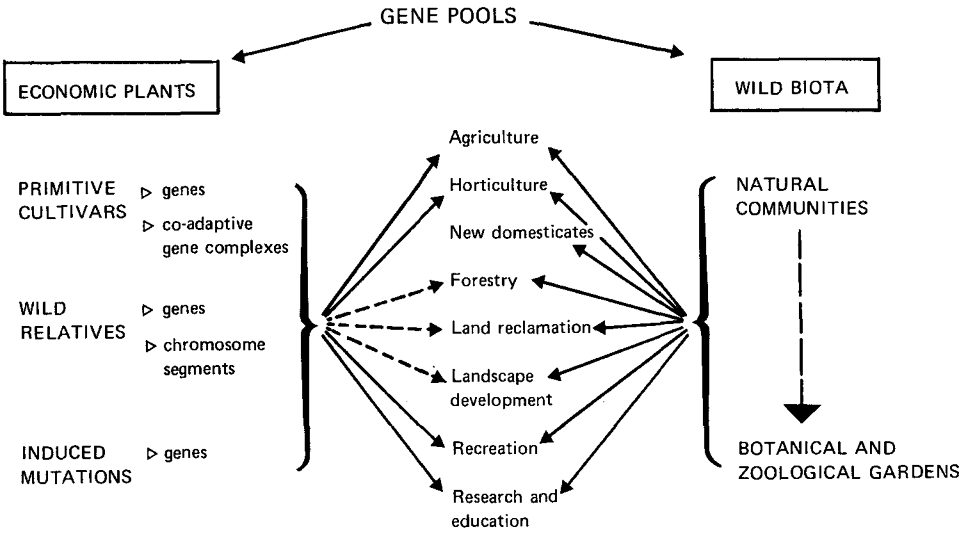

FIGURE 1.—Impact areas of domesticated and wild gene pools.

the transfer of chromosome segments, first accomplished some years ago and beginning to be used more extensively, has been used principally as a device for transferring single resistance genes from cross-sterile relatives. No doubt primitive and wild gene pools will continue to serve as important sources of genes for resistance to parasites or for characteristics indicated by advances in science or technology or by changing demands of the consumer. Nevertheless, as MARSHALL and BROWN (1974) point out, "the aim of conservation" is to collect and conserve adaptive gene complexes. As emphasized by BROCK (1971), in many circumstances induced mutations may represent a more efficient source of single gene variability than gene pools conserved from nature. Yet it is extremely unlikely that populations treated with artificial mutagens can replace natural gene pools as a source of coadapted gene complexes which are of fundamental importance in the adaptation of populations to their environment (DOBZHANSKY 1970). In fact, in the use of plant gene pools little consideration has been given to adaptations which must have evolved over hundreds or thousands of generations under cultivation in diverse environments, including various stress conditions (see FRANKEL and BENNETT 1970). Most plant breeders continue to rely on adaptations derived from the relatively narrow gene pools of present-day cultivars. But there are significant exceptions. VAVILOV advocated the use of geographically (and ecologically) distant parents and of primitive germ plasm from diverse sources; and BORLAUG, one of the most successful plant breeders of our time, has drawn on such a diversity of genetic resources. Diverse adaptive gene complexes could be of immense value to the imaginative plant breeders of tomorrow.

I conclude that the most important genetic resources of economic plants are the indigenous populations of traditional agriculture. They are also in the most immediate danger of extinction through replacement by modern cultivars. The wild relatives are not nearly as exposed, but there are exceptions. Forest species can be virtually wiped out through large-scale land clearing for agriculture or for replanting with exotics (see FRANKEL and BENNETT *loc cit.*). The progenitors of various mediterranean vegetable crops are threatened by intensification of land use (ZOHARY, personal communication), and wild fruit tree species are in jeopardy in Malaysia (HO COY CHOKE 1973). Foresters urgently call for gene pool conservation of threatened communities (see FRANKEL and BENNETT *loc. cit.*), and other wild plants of economic significance could be similarly protected within a framework of ecosystem conservation.

What then is the current state of the primitive gene pools? There are many varietal collections of most crop species. With some notable exceptions their holdings of primitive material are neither large nor representative nor well documented. Until recently they were exposed to natural selection, genetic drift, hybridization, parasites, or unsuitable growing conditions. As we shall see, all this can be largely avoided; but many of the existing collections have been sorely depleted. Although steps have been taken in some major collections to avoid further losses, which is important since much of the material they hold may no longer exist anywhere else, it is imperative that as much as possible of what is left *in the field* is expeditiously and effectively conserved.

Assembly and conservation: Primitive cultivars cannot be preserved *in situ*, since this would mean the preservation of farming systems, which, in the face of rapidly changing technologies, is an economic and social impossibility. Fortunately this is not needed since representative samples can be collected in the field and safely preserved for long periods.

A collecting program for any species requires information on the areas where collections are to be made. Such information is now available in outline (FRANKEL 1973). With growing interest in their own genetic resources, scientists in the developing countries where the centers of diversity are situated, are playing an increasing role in tracking down and collecting their own genetic treasuries. Clearly they stand to gain most.

Sampling procedures must be devised which accord with the limitations of time, personnel, distribution and accessibility of sites, and available resources (see FRANKEL and BENNETT 1970, especially Chapter 13 by BENNETT; MARSHALL and BROWN 1974). Ecological considerations and variation patterns will help to formulate strategies on the number and distribution of sampling sites. Unfortunately, as MARSHALL and BROWN point out, there is little quantitative information available on genic variation between and within population of cultivated plants which would facilitate objective decisions, including decisions on the number of plants to be sampled per site. Based on the reasoning that "the great majority of common alleles or allelic combinations presumably represent adaptive variants maintained in populations by some form of balancing selection" (DOBZHANSKY 1970), and that rare variants are difficult to find, they propose a sampling aim of "at least one copy of each variant occurring with frequency greater than 0.05." A consideration of theoretical distributions of allelic frequencies and of population studies on organisms with different breeding systems suggested a sample size of 50–100 random individuals per site, as against much larger numbers recommended by previous authors (e.g., BENNETT 1970).

Conservation procedures have also been clarified and, fortunately, greatly improved and simplified, at least in the case of seed-propagated plants. Plants are most safely conserved in a dormant state, i.e., as seeds, which avoids the risks and expense of growing stocks repeatedly (see FRANKEL and BENNETT (1970); FRANKEL and HAWKES 1974). Viability and genetic integrity can be maintained at a high level for many years provided seeds are stored under appropriate conditions of temperature and moisture content. There is a correlation between viability and genetic damage to the extent that as long as viability is above 85–90%, chromosome damage and mutation remain at reasonably low levels (ROBERTS 1974). Equations predicting viability as a function of temperature and moisture content have been confined for a number of species and are expected to apply to many others (ROBERTS 1972). Seeds of most species can now be preserved for decades not only safely but cheaply, and this may be extended to centuries once more experience has been gained in storage at sub-zero temperatures. Seed stored in a fully imbibed state (VILLIERS 1974) or kept at the temperature of liquid nitrogen (SAKAI 1974) may altogether avoid the risk of genetic damage. Both are being further explored. Even when regeneration becomes necessary this can only marginally affect population structure and gene frequencies provided it is carried out under conditions which safeguard the reproduction of all components of a population.

In plants which reproduce vegetatively, regeneration from tissue culture avoids the expense and the risks involved in maintaining whole plants. So far only meristem culture can be used for long term conservation because of the *in vivo* and *in vitro* chromosomal instability of other tissues (MOREL 1974; D'AMATO 1974). Once they are assembled, safely stored and adequately documented, genetic resources become available to the scientific community and through it to society, for the benefit of this and future generations, for as long as crops are grown.

Social responsibility and action: Those who believe that the scientist's social responsibility does not end with scientific publications may be reasonably satisfied with the contributions made by geneticists to national, international and United Nations action programmes, with the International Biological Programme (IBP), in collaboration with FAO, playing a major part. A global network of genetic resources centers was unanimously endorsed by the United Nationas Conference on the Human Environment, Stockholm, 1972 (FAO 1973; FRANKEL 1974). Fortunately, essential salvage can be rapid and, like long term conservation, does not make excessive demands on funds. What is now needed is urgent and concerted action.

WILD SPECIES

Forms of conservation: Little thought has been given to the genetic resources of wild biota—for the obvious reason that they are assumed to be self-renewing in natural communities (see FRANKEL 1970). But these communities are now disappearing at an unprecedented rate. The distinguished Australian biologist, SIR MACFARLANE BURNET, believes that "there is now very little hope that any of the potential food growing areas of the globe can be left in their natural state" but that some marginal areas may be left intact "at least for a few more generations" (BURNET 1967). With intensification of land use even hedgerow, roadside and wasteland, the habitats of many species such as those mercurial butterflies so fruitfully studied by E. B. FORD and his associates (see FORD 1971), are likely to vanish. Even in Australia with its large expanse of land, many wild species have become extinct and many more are in jeopardy and will become extinct unless measures are taken for their protection. DAY (1970) stresses "the ever increasing significance [of National parks] in providing sanctuaries for Australia's unique flora and fauna." Projecting ourselves a mere century ahead one must assume that many of the remaining species almost anywhere in the world will *depend on organized protection for their survival.* The discussion which follows is based on this assumption, and on the premise—discussed in the last section—*that wild species should be preserved for posterity*. Taken together these two statements predicate long term conservation under conditions which facilitate continuing evolution.

In any system of conservation one can distinguish three classes of parameters (Table 2): (1) a socially conditioned parameter, concerning the time scale; (2) an ecological parameter—the biological system of conservation; and (3) the genetic or evolutionary parameters—variation and selection. Table 2 sets out these parameters for wildlife conservation in natural communities (A), in zoological and botanical gardens (B), and, by way of contrast, also for domesticated plants (C). Comparisons between A and C are revealing:

1) In domesticates, time perspectives are short—one does not even know what crops will be grown only 50 to 100 years hence. For wildlife conservation there is no socially conditioned "time scale of concern" (Figure 1); like evolution itself, wildlife conservation is "open-ended" (DOBZHANSKY 1967);

2) in domesticates, as we have seen, conservation in the form of population samples in a dormant state is effective and economical; in domesticates, conservation *in situ* is not practicable, whereas in wild species this is the only form of

TABLE 2

Social and biological parameters of conservation

	A. Natural communities	B. Zoological and botanical gardens	C. Domesticated plants
The social parameters			
● Time scale of concern	unlimited— 10,000 years?	uncertain	limited— 100 years?
The ecological parameters			
● Units of conservation	populations	specimens	population samples
● Method of conservation	*in situ*	semi-domestication	seed storage, tissue culture
The genetic parameters			
● Generation of variation	self-generating	restricted gene pools	controlled by man
● Dynamics of adaptation	natural selection		selection by breeder

conservation which extends the hope of survival in a natural state, i.e., under conditions of continuing evolution;

3. in domesticates, the conserved germplasm is a source of breeding stocks for recombination; the generation of variation and the process of selection are controlled by man. Wild species in natural communities are dependent upon variability generated by their genetic system and are kept in balance with environmental change by natural selection. Conservation is dynamic in natural communities, static in domesticates.

Conservation in captivity, in zoological and botanical gardens, is akin to conditions of domestication (Table 2B). But there are the additional limitations of small numbers, greatly restricted gene pools, risks of disease, neglect or loss of social support. Clearly, this is an evolutionary dead-end.

Endeavors to regenerate threatened or vanishing species fall somewhere between managed and natural communities. Presumably it is important that the initial population (s) are equipped with adequate genetic variation. For work with plant species representative collections which can be kept as seeds for long periods could serve as a useful resource. Such a collection is being assembled at the Royal Botanic Gardens, Kew, though for a different purpose (THOMPSON 1973). A study of the size and genetic structure of regenerating populations, beginning with the founding generation, could be of considerable interest as it might provide valuable leads for the conservation of rare species.

To conclude: Management under conditions approaching domestication is practicable for relatively short term conservation of selected wild species, but long term conservation of a large range of species is feasible only within natural communities.

Genetic aspects of the conservation of natural communities: The siting, size, design and management of reserves are the result of ecological, economic, social and political circumstances. This is inevitable. But it is necessary to emphasize that the effectiveness of reserves as long term sanctuaries may be conditioned by the genetic system of conservation. The aim must be to optimize conditions for continuing evolution. This is an important but largely unexplored issue. There is an urgent need for clarification since opportunities are fast running out. Here I can do no more than raise some of the relevant questions.

The prime parameters are the level and distribution of variation, the size of the minimum viable population, and the optimal and minimal sizes of reserves. Specific answers will depend on such factors as species composition and the life cycle and breeding systems of the component species.

It is known that variation is substantial in most, though not in all natural populations, and at least part of it is adaptive. We need to know the minimum population size which is likely to yield a required level of variation. Subpopulation structure, inter-population variation and gene flow are further parameters which must affect variation and adaptation in long term conservation. It is not only the genetic variation between individuals but genetic differences between populations—the way in which a species gene pool is apportioned and patterned among component populations—which affords the flexibility for evolutionary persistence.

Very little is known about long term trends in natural populations, even at a numerical level. The studies conducted by MAIN (1961) and MAIN and YADAV (1971) on the marsupial fauna and elements of the flora on offshore islands in Western Australia are of special interest. The times of separation of these islands from the mainland are between 15,000 and 7,000 years ago. Assuming that their flora and fauna corresponded with those of the mainland at the time of separation, conclusions can be drawn on the area and population size required for survival of marsupial species. The minimum viable population appears to be between 200 and 300 animals. One of the largest islands, of 22,000 hectares, has retained a representative flora and fauna, and this is judged to be the minimum size for a nature reserve in this environment. Now that objective methods are available through the application of protein electrophoresis and immunological techniques it should be possible to compare the levels of variation within and between populations of different sizes on islands and the mainland.

Studies on island populations of lizards in California, in the Adriatic and the West Indies by SOULÉ (1972, and personal communication) and SOULÉ *et al.* (1973) show that island size is correlated with overall variation. On very small islands there occurs "a significant attrition of allelic variation," the critical variable presumably being population size—estimated at between a few hundred and a few thousand—rather than size of the island. This "small island effect" was found on all the six small islands which have been examined, hence is attributed to near extinction in times of drought rather than to extinction followed by recolonization. The age of the islands is about 15,000 years. SOULÉ concludes that if one wishes to secure long term survival in a natural state, population sizes should be of the order of 10^4 or more. The evidence further suggests the need for *multiplicity* and *diversity* of conservation sites as a safeguard against environmental attrition.

It has been argued that population subdivision maximizes the potential rate of evolution (WRIGHT 1970). But it will be rash to conclude that many small reserves are more effective than fewer larger ones. In practice a balance has to be struck between partially conflicting considerations. But what is needed is much more information on the genetic parameters of conservation. Comprehensive "date line" studies should be initiated in selected reserves, which even at their inception will provide information on the population structure of a range of species which would be useful not only in designing reserves, but in landscape development to which I refer in the next section.

Motivation: A commitment which is to involve future generations must carry the strongest conviction in the basic validity of the undertaking. The preceding discussion was based on the premise "that wild species are to be preserved for posterity." We must now examine the validity of this premise.

There is no need for restating the general case for nature conservation which now is familiar to all. I shall confine myself to two complementary aspects of genetic relevance: (1) that natural ecosystems are gene pools of increasing importance for human activities; and (2) that the continuing existence, hence continuing evolution, of life forms *other* than those we use is a human need.

Natural gene pools: The middle column in Figure 1 lists areas of impact of wild biota. The diversity is striking and the extent, already considerable, is likely to grow in the future. A few examples must suffice.

There are great reservoirs for new tree fruits in the forests of Latin America and Southeast Asia, and for ornamentals in the Australian bush. Australian gene pools of *Eucalyptus* spp. are of immense importance to large scale users of the genus in other continents, as are those of Mexican pines to tropical areas. New industrial processes will increasingly require new raw materials, especially after the exhaustion of fossil resources. Once the productive resources of the sea, especially of coastal waters, are intensively exploited, gene pools of aquatic plants and animals will acquire significant roles. Landscape development for recreation and other purposes will grow in importance as new methods of food production free marginal agricultural land, especially around population centres.

These, and other developments which cannot as yet be foreseen, will require gene pools for exceeding the genetic resources of commercial suppliers or of botanical and zoological gardens. Far from being confined to present-day developed countries, such developments will primarily concern the tropics where the largest and richest near-natural gene pools remain. Indeed, wisely designed nature reserves may be a greater source of future wealth than some of the current development involving wholesale destruction of existing ecosystems.

An evolutionary ethic? So far this discussion has been unquestioningly anthropocentric. I have argued that the conservation of wild biota is justified because they are useful to man, and that long term conservation is feasible only in a state of continuing evolution. I am now raising the question of whether continuing evolution itself has an *intrinsic value*. Before attempting an answer I must clarify the basis of such a value judgment.

Here also there can only be an anthropocentric basis. I am in agreement with JOHN PASSMORE, the author of an excellent book, *Man's Responsibility for Nature*, that any other basis, such as "the right to life," or "the sacredness of nature," is mysticism hence outside scientific reasoning (PASSMORE 1974). But there is another and wholly materialistic reason. Even now, terrestrial ecosystems which have not been substantially modified by human impact are few and far between. In another century there may be none. It follows that if some natural communities are to be preserved for any reason whatsoever, this can be done only, in VAVILOV's words, "at the will of man."

I can therefore re-phrase my question more precisely: has the continuing evolution of wild species a value for man other than an utilitarian one? To make an answer possible, I must define the issue more closely. What is at stake is not the extinction of individual species, though the current rate of loss in many parts of the world is high and accelerating. This may not be without precedent in evolutionary history. But what is without precedent is the predictable destruction of habitats for what remains of the earth's natural and semi-natural communities and of most of the species they include. Without deliberate protection few of these communities will have a chance of survival; nor does the shrinkage of undisturbed habitats offer a promise of evolutionary replacement.

This is a situation outside past experience, a confrontation between man and other biota which in the short space of two or three generations could imperil a large proportion of the wild species that now remain. Man would direct the evolution of biota that are of use to him, and the only ones retaining their evolutionary independence would be those he is unable to suppress. This is heavily overdrawn; but the tendency is there to see.

Even if we reject the prospect of becoming the arbiters of evolution, can we assume that future generations will share our concern? PASSMORE's review of Western attitudes to nature through the ages does not encourage confidence.

Yet if one thing about the future is certain it is that cultural, technological, economic, and possibly biological man a century or two from now will differ more greatly from us than we differ from the early agricultural settlers. Future man is more unknown and unpredictable than at any time in history. Hence at this point of decision-making it may be our evolutionary responsibility to *keep evolutionary options open* so far as we can without undue deprivations for those least able to bear them. This is a modest precept, but as much as is at all likely to be socially acceptable at this time. It may grow into an evolutionary ethic if and when men come to regard other species as an essential part of their own existence.

Perhaps our greatest difficulty stems from the contradictions of time scales: evolutionary time is compressed into historical time and made subject to decision making on a socio-political time scale (Table 1, last two lines).

The role and responsibility of the geneticist in the preservation of the genetic estate is threefold. First, as I have indicated earlier, we should get to know much more about the structure and dynamics of natural populations and communities. This is an open-ended task, hence the problem setting must be highly selective. Second, even now the geneticist can play a part in injecting genetic considerations into the planning of reserves of any kind (FRANKEL 1970). In this he can be more mercurial than the conservationist, since we are concerned with populations wherever they are, and not only with conservation fortresses. I cannot elaborate on this, but the genetic estate has many facets, and there should be no need for establishing genetic ghettos. The exclusion of man is not essential to genetic conservation—on the contrary, near complete exclusion will reduce support and is likely to limit size and diversity of reserves. Finally, reinforcing the grounds for nature conservation with an evolutionary perspective may help to give conservation a permanence which a utilitarian, and even an ecological grounding, fail to provide in men's minds.

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