RESTORING DAMAGED ECOSYSTEMS: IS PREDISTURBANCE CONDITION A VIABLE OPTION?

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Abstract. The recent surge of interest in restoration ecology is accompanied by a growing recognition that if we are to diminish the global rate of species extinction and rehabilitate those species remaining, society, worldwide, must preserve the good condition of its remaining ecosystems; however, public support of such an effort will diminish if more is promised than can be delivered. Ideally, we should restore badly damaged ecosystems to predisturbance condition for the short-term benefits (real or imagined) to be gained therefrom. This would exclude New York City, but not most tropical rainforests. All too frequently restoration may not be possible for a variety of reasons. In this connection, the following topics, together with some illustrations of what might be realistic in terms of present capabilities, are discussed: (1) disturbed ecosystems and global loss of species, (2) natural processes and the return to predisturbance condition, (3) lack of a robust predictive capability, (4) legislation, and (5) responsibility for and termination of restoration efforts.

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INTRODUCTION

The following topics are discussed in this manuscript:

(1) Disturbed ecosystems are now the norm and the consequent extinction of species is alarmingly high;

(2) Even if the stress that produced the disturbance is removed or markedly reduced, unaided natural processes may not result in a return to predisturbance condition;

(3) The lack of a robust predictive capability in ecology makes the outcome of both natural and managed recovery uncertain;

(4) Legislative and other "practical" obstacles to restoration ecology exist; and

(5) Responsibility and termination of restoration efforts should be based on sound judgment.

Readers wishing more evidence on case histories will find them in Cairns et al. (1977; includes the Thames River and Lake Washington), Holdgate and Woodman (1978), the journal *Restoration and Management Notes* (University of Wisconsin Arboretum, Madison), Bradshaw and Chadwick (1980), and Cairns (1988a).

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DISTURBED ECOSYSTEMS NOW THE NORM

Most of the world's ecosystems have been disturbed by human activities, resulting in acid rain, global carbon dioxide buildup, hazardous chemicals, deforestation, overgrazing, water diversion and storage projects, surface mining, agriculture, and urbanization, to mention a few examples. The species inhabiting these ecosystems have undergone remarkable evolutionary changes, enabling them to survive in such rigorous environments as the thermal vents on ocean floors and the extremes of the Arctic and the desert. Some ecosystems are even dependent on specific types of disturbances, such as fires and floods.

These superb adaptations to natural disturbance have not proven equally effective in coping with most anthropogenic disturbances. Compelling evidence for this can be found in the book *Biodiversity* (Wilson, 1988), which represents the proceedings of a symposium co-sponsored by the National Academy of Sciences and the Smithsonian Institution. Abundant evidence for sweeping global ecological change coupled with a staggering rate of loss of species is documented in *Biodiversity*. It is worth noting that the world's species are not evenly distributed geographically: the highest species richness is in such ecosystems as tropical rainforests which are being rapidly destroyed. It is also worth emphasizing that this vast loss of species is occurring before an inventory of the planet's species is completed. Inventorying, of course, means naming and cataloging the species together with their location and not necessarily describing their ecological function, life cycles, etc. Since species are interdependent and since the estimated rate of loss is so high, it is at least conceivable that up to half the earth's species could be lost in the next fifty years (Cairns, 1988b).

Suppose both (a) rate of species loss could be dramatically reduced to an approximation of that typical over geologic time and (b) destruction and degradation of the world's ecosystems could be arrested. Would it then be possible to restore the disturbed ecosystems to a close approximation of their predisturbance or "original" condition? Although the term *original condition* is routinely used, I prefer *predisturbance condition* as a more precise term (other options are covered in Figure 1). For example, it is certainly beyond our capabilities to restore the earth's ecosystems to their condition during the Pleistocene, but even if we could do so, would we wish to do so since the climate is so different now? A more extensive discussion of the terminology in the field of restoration ecology may be found in Jordan et al. (1987) or Cairns (1986). Major global restoration will be exceedingly difficult with the earth's present population and level of industrial activity. Most likely, efforts should be restricted to preserving relatively undisturbed or partially recovered ecosystems still remaining, and attempting to restore selected ecosystems such as the Gunacaste Dry Forest (Janzen, 1988).

The human species will probably survive if unprecedented ecological destruction continues at its present rate, but our society may not survive in its present form. We are already hearing disquieting predictions of the consequences of global climate change, their effects on the ecosystems and on agricultural production, and the possibility of melting polar ice flooding the coastal areas.

UNAIDED RECOVERY FROM EPISODIC DISTURBANCE

Recently, some students, a colleague, and I have been studying unaided recovery from brief episodic disturbances. In the late 1800s extensive silver mining was done on the western slopes of the Rocky Mountains north of Gunnison, Colorado. Some mining sites were in or near the town of Gothic, also in Colorado, which sprang into existence precipitously, rose to a population estimated to be in excess of 5,000 persons (many more picked up their mail in the town), and then after a few years of operation declined to include one person named Judd, who remained after the silver mining operations ceased. Mining was accompanied, of course, by such other supporting activities as lumber mills, a hotel, saloons, restaurants, newspapers, mercantile establishments, and the like. After the mining operations failed, the town site was essentially abandoned, and the town saw little human activity, with the exception of occasional visits from outsiders and the doings of Judd, the one man who remained.

In the 1920s, the "ghost town" of Gothic was purchased by a group of biologists under the leadership of John C. Johnson, Sr., who formed the Rocky Mountain Biological Laboratory (RMBL), an independent incorporated organization. When RMBL was founded, the increased activity in the area was less ecologically destructive because biologists came to study the species inhabiting the high altitude (9,500 feet) ecosystems. In addition, because snow is present for most of the year, human activities are restricted almost entirely to summer time. It is important to note that the Laboratory made no effort to develop a management program for restoring the ecosystem, but merely observed naturally occurring events.

Preliminary studies, based on imperfect but surprisingly detailed information available from that period, indicate that, in some instances, even though approximately 100 years have passed since the major disturbance occurred, the ecosystem clearly does not correspond to its condition in the late 1800s. The sites of specific activities, such as a blacksmith's shop, are still ecologically quite different from the surrounding areas. Topographically, the area where the blacksmith's shop stood does not appear greatly different from the surrounding area, since it had no foundation as did the mercantile stores, which are ecologically quite distinct from the surrounding areas as well. In terms of species composition, biomass, diversity indices, and

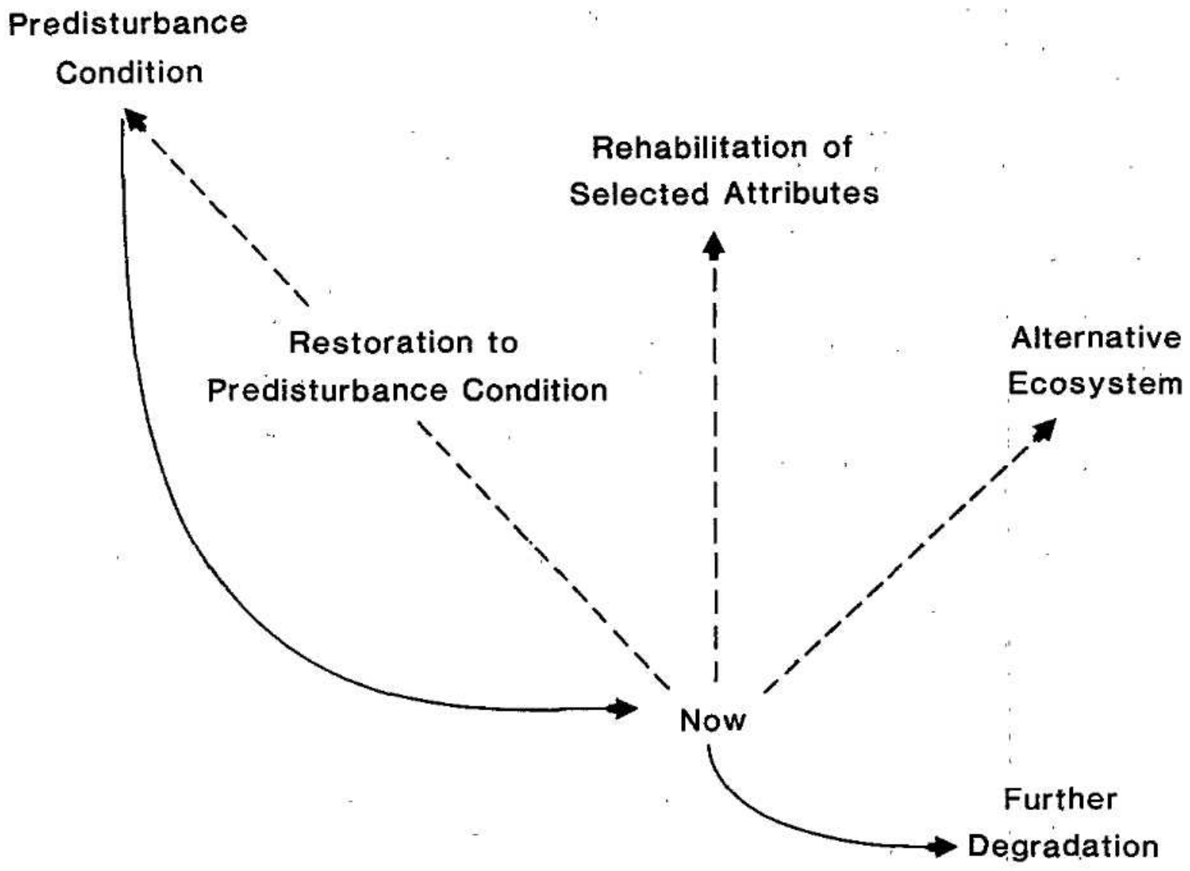

Figure 1. Policy Options for Management of Disturbed Ecosystems
(Modified from Magnuson et al., 1980)

other relatively easily measured characteristics, the disturbed ecosystems do not closely correspond with what appear to be comparable areas that were outside the influence of major mining activities.

Successional Processes

Some terrestrial ecologists have the view that successional processes (replacement of some species by others) lead to a "climax condition," which then remains relatively stable over a substantial period of time. If disturbance causes a regression to an earlier successional stage and the successional process then follows the same track it did before, one might expect the system to achieve complete recovery eventually. This does not appear to be the case since: (1) the species representing the earlier successional stages may no longer be present for reinvasion, and (2) because other species, including exotics, not present during the earlier developmental period may be the post-disturbance colonizers. Thus, one has a species composition not characteristic of an earlier successional stage that is quite likely to influence succeeding successional stages. It is not certain that, given more time, a particular climax will not be established, but it does seem likely.

If one takes the alternative view, namely that all ecosystems are dynamic and continually changing (albeit at rates that are sometimes incredibly slow given the human perspective of change), then restoration to predisturbance condition would not be as appropriate as restoration to the present condition of a comparable undisturbed system. If one takes this view, earlier successional stages are only relevant if they are required to reach present condition of comparable undisturbed ecosystems. If the recovery process is rapid and likely to result in a close correspondence with comparable undisturbed contemporary ecosystems, then lag time becomes less relevant.

The importance of all of the above discussion may be greatly diminished by the fact that the successional process and other events in ecosystems are strongly influenced by the **sequence** of climatic conditions. For example, in the Gothic, Colorado, area in spring 1988, the winter snowpack was much lower than average, and roads that are sometimes impassible to vehicular traffic in early June were not only free of snow but actually dusty. There have been other dry years and "early springs"; however, a particular sequence of climatic circumstances over a period of 10, 20, or 100 years is unlikely to be repeated. Since species in ecosystems are influenced by both short- and long-term events, the inability to re-create a special sequence may mean that attempts to restore to predisturbance condition are unlikely to succeed because of this fact alone. An alternative view has been expressed by Patten (1975): namely, that natural selection operates to rid ecosystems of undesirable nonlinear characteristics. A more extensive discussion of these and related problems is found in McIntosh (1980). Gleick (1987) examines the problem of weather predictions using Edward Lorenz's results as an example. Lorenz constructed very simple systems that had the apparently conflicting properties of being deterministic (i.e., precise equations described the behavior of parts) and having results that were unpredictable. This sounds very much like ecology.

LIMITATIONS RESULTING FROM THE LACK OF PREDICTIVE CAPABILITY

Whenever an organization considers investing money in a restorative effort, willingness to do so is directly related to the desirability and **certainty** of the outcome. Unfortunately, the outcome is usually highly uncertain because the field of ecology lacks a robust predictive capability.

The well-known Welsh ecologist John Harper (1982) feels that ecology has tended to be highly descriptive in nature, but has thus far made little progress toward reaching maturity as a rigorous experimental and predictive science. In Harper's opinion, one of the reasons for this is that ecology is using conceptual equipment that may be inadequate for the task of predicting ecological events. He also feels that

> so long as ecological work remains basically descriptive, these weaknesses are not evident because validation of predictive models etc. is either not done or is not done as it should be.

Harper (1987) feels that research in ecology (particularly plant ecology) has been dominated by description or correlation, which are only the preliminaries to posing and answering questions about causation. Bradshaw (1987) calls restoration an acid test for ecology and clearly does not expect sensational results in predicting the outcome. Diamond (1987) points out that the traditional approach of ecology is reductionist and that restoration provides new knowledge not offered by traditional approaches because it is synthetic. Thus, the prospects for predicting the outcome of rehabilitation or restoration efforts with any reasonable degree of certainty are not good (Cairns, 1986, 1987). This means that abundant research opportunities exist in restoration ecology, but it also means that we must either begin major restoration undertakings before an adequate scientific informational base and methodology are available or postpone this activity until the research has been completed.

In view of the dire circumstances described in detail in the book *Biodiversity* (Wilson, 1988), preservation may not be enough, given the degree of ecological destruction that has already taken place. Therefore, much of the research in restoration ecology must take place on already damaged sites which may not, for various reasons, always be ideal in terms of pre-existing information, habitat size and type, and total freedom during the restoration process from human activity, etc. Were it not for the splendid example already set by Janzen (1988) and other examples elsewhere in the world, critics might well have plausible doubts about simultaneously carrying out basic research under circumstances where political, economic, social, and other activities intrude. On the other hand, since most restoration efforts will not be successful if one of the requirements is exclusion of all human activities, what is unsatisfactory to a theoretical ecologist may, in fact, be far more realistic in terms of the task to be accomplished than the purely theoretical research would be. Additionally, with research funds today becoming increasingly scarce, it is unlikely that they will be available from the usual sources for the research projects on the scale of ecosystem restoration.

Fortunately, the process of decision analysis developed for other purposes is as admirably suited for making decisions where the outcome is highly uncertain as it is in restoration ecology (Maguire, 1988). Even if the science is not adequate to the task at present, the rapid accumulation of information in recent years provides compelling evidence that the present situation will not persist long once major attention is given to this need. Therefore, the theoretical underpinnings of restoration ecology, including interactions with other disciplines, will be rapidly generated. Unfortunately, validation of the predictions based on this new information will undoubtedly lag in time, probably in excess of the human life span, for many. The error correcting feedback loop, common in most predictive modeling, will be present, but with a longer lag time than is common for such things as evaluating the hazard of toxic chemicals. The validation of the predictive models is exceedingly important, and certain short-term predictions can be validated or falsified quite quickly (e.g., export of nutrients from the ecosystem). If the latter are validated, confidence in the outcome of the rehabilitation process will increase. Although distinct drawbacks to the scientific underpinnings for this endeavor exist, many formidable practical problems that may take fairly long periods of time to resolve also exist. Some illustrative examples follow.

SOME "PRACTICAL" OBSTACLES TO RESTORATION ECOLOGY

Present U.S. legislation regarding restoration efforts following deliberate or accidental damage to an ecosystem is often so prescriptive that commonly little or no research is possible if one wishes to comply fully with existing legislation; some of the legislation is so prescriptive that often the most obvious common sense measures cannot be taken.

For example, surface mined areas in the steeply sloping central Appalachian region are often returned to an approximation of the original contour. The resultant landform is steep, erosive, and frequently unstable, especially when revegetation processes are slow. In these circumstances, successful reclamation might be defined as the process that prepares mined land for productive (e.g., agriculture, housing) post-mining use (Daniels and Zipper, 1988). This should serve the needs of society (e.g., by reducing or eliminating runoff deleterious to adjacent ecosystems) as well as the landowner.

Another consideration has to do with responsibility for the restoration efforts that typically require many more years than the mining itself. In the United States, it is possible for a small company to mine an area and then declare bankruptcy before the restoration practices mandated by legislation can be completed. Therefore, bonding is required. But the bonds may be too low to adequately cover the cost of reclamation if the operator defaults. The questions are how long should the bond be held and how could one demonstrate that the restored ecosystem would be stable and persistant once the management practices ceased? One method requires that all restoration efforts be made in the first year; and then the system is to be untouched for a multi-year period (e.g., five years), showing that a balanced biological community could persist for at least that period assuming that if it persisted for five years, it would do so more or less indefinitely. Problems develop with this approach during severe drought (as has been the case), when in the third year of the "hands off" period some form of watering would be a good management alternative. Similarly, crucial species that disappear during this "hands off" period might well be replaced without damaging the integrity of the balanced biological community, leading to a swifter establishment of equilibrium. If the legislation is too prescriptive, this management alternative may not be permitted.

These over-simplified descriptions of rather complex situations demonstrate clearly that both the information base and a diverse array of methodology will be developed more rapidly if the legislative system is flexible and amenable to modification on a case-by-case basis. Ecologically, this makes sense because no two ecosystems are precisely the same. In terms of information generation, this makes sense because the use of a diverse array of management strategies will enable a swifter selection of those producing the most certain and desirable outcomes. Such a system is difficult to defend because it is thought to be more amenable to corruption and because the costs to the institutions responsible for the restoration are less predictable.

The corruption aspect might be mitigated by insisting that the organization causing the damage pay a fixed sum toward restoration—a sum of money that the prescriptive legislation would require. Any expenditures beyond that would be borne by society in some way when research information of particular value will be generated. I realize that one could easily object to this on the grounds that the organizations causing the damage should pay both the actual restoration costs and the research costs so that the restoration efforts are successful; however, as a practical matter, this seems highly improbable. Restoration research involving a societal contribution will work best with increasingly effective local stewardship, where local citizens become well informed about restoration practices in general and have a science advisory board for the highly technical problems.

Ironically, some of the fiercest resistance to restoration efforts may come from classical biologists who have been comparatively passive with regard to the destruction of the environment by developers, industry, natural resource organizations, etc., but who are critical of management efforts to restore damaged ecosystems (e.g., Wyngaard, 1985). Possibly they are equating present condition with pristine condition.

Most of the world's ecosystems have been significantly altered. In fact, many biological field stations are on sites that have had major damage (Cairns, 1988). The two with which I am most familiar, having been at one or the other continuously in the summer from 1961 through 1988, are the University of Michigan Biological Station (UMBS) at the tip of the lower peninsula of Michigan and the Rocky Mountain Biological Laboratory (RMBL) on the western slope of the Rocky Mountains near Crested Butte, Colorado. UMBS is on a site that was heavily logged around the turn of the century; all the trees were removed and their limbs and smaller branches burned on the spot. Thus, the heavy logging was followed by fairly intense fires. Pictures of this may be found in Cairns (1980). RMBL is on the site of the old mining town of Gothic, occupied by thousands of people in the late 1800s.

Photographs and newspaper accounts of the level of activity on this site indicate that the original vegetation was severely altered. Both field stations suffered extreme ecological disturbance for a relatively brief period of time, and unaided natural recovery since then has been sufficiently successful to enable research biologists to carry out a number of research projects that have been published in peer-reviewed professional journals, some quite prestigious. The recovery, however, does not even closely approximate the predisturbance condition. Both appropriately accord the ecosystems the fullest protection possible, and they are treated as if they were essentially pristine systems. At UMBS, which on the main site has approximately 9,000 acres, a proposed clear-cutting and burning of roughly an acre (in an attempt to re-create the original disturbance as both a demonstration area for students and to get some information on what the post-disturbance condition was like) was strongly resisted by some of the biologists involved with that institution. The fact that the project went forward indicates that the opposing scientists were a minority—albeit a vocal one. At RMBL, one faculty member objected to attempts to revegetate an abandoned road in the middle of the facility because some organisms dissimilar to those in adjacent areas might colonize the area. Additionally, the introduction of species similar to those inhabiting the area, but from a site adjacent to the laboratory site itself, was criticized on the grounds that it might interfere with studies in pollination biology being carried out by others—although these research investigators themselves felt that the removal of flowers would resolve this issue.

The purpose of mentioning these details is not to belabor the objections raised, since peer criticism is the very foundation of advances in scientific theory, but rather to acquaint non-biologists with the strong possibility that some biologists will object to specific restoration projects although they might espouse restoration in principle. In short, as is the case with almost all controversial issues, scientists will present opposing views on both sides when a specific project is proposed.

One of the largest of the practical problems is almost certainly ownership of the disturbed ecosystem. Presently, in the United States, disturbed ecosystems are owned by private citizens, corporations, and both state and the federal government. Within some ecosystems, ownership may be divided among two or all three of these categories. Even for the case of public lands held by state and federal governments, a restoration project that prohibits certain present uses may be fiercely resisted.

For example, drivers of "off-the-road" or "all terrain" vehicles might have become accustomed to using certain areas for their recreation. Professional literature offers abundant evidence that these vehicles can cause extensive damage, particularly in fragile ecosystems. They would almost certainly not be compatible with a restoration effort, and even under the best circumstances, stringent regulations regarding both frequency and areas of use would have to implemented. Enforcing these would be extraordinarily difficult, and the record for voluntary compliance has not been exemplary. Private citizens and corporations owning disturbed ecosystems do not like to be told how to manage their property. Precedence has been set for this, however.

For example, the Office of Surface Mining (OSM) has the authority to regulate reclamation of surface mined sites. In Great Britain and some other areas of the world, including the United States, construction on private property must be authorized by a review organization, and permission is likely to be denied if the project is aesthetically displeasing in an area where aesthetic quality is important. There are other examples such as this, and the owners of private property everywhere in the world are under increasing pressure to use their possessions so that the public welfare and the property rights of their neighbors are not impaired.

In the United States, storage of hazardous wastes on private, corporate, or government property is now more stringently regulated than it was a few years ago because the detrimental effects frequently go beyond the property line or might well go beyond the property line due to a design failure, etc. Including ecosystem condition in the mix of regulations on ownership on private property would merely be an extension of this concept. Additionally, private property owners who agree to management practices that will enhance survival of rare, threatened, or endangered species or protect unique ecosystems may now be included in a special program organized by the Nature Conservancy in the United States. Governmental organizations could easily give special tax benefits (i.e., reduced taxes), especially if the owners sign an agreement to honor these conditions for a substantial period of time and this responsibility must be accepted by any subsequent purchasers of the property.

TERMINATION OF RESTORATION EFFORTS

Whenever the outcome is uncertain, as it will be for all restoration projects until the ecological predictive capability improves, one must assume that some efforts will be so far from expectation that the project should be terminated and a fresh start made using a new design. At the present time, I know of no criteria or guidelines in the professional literature for addressing this problem. Clearly, the persons most deeply involved with the restoration project may become emotionally involved with its success and therefore wish to continue with the present course of action, even though it is not following predictions originally made. In the case of an organization such as a surface mining company paying for heavy bonding, an extension of this bonding resulting from starting over again would be an additional financial burden.

In the case of projects on government property or on public property, even an ecologically unsuccessful project may appear successful to laymen because a devegetated area has been revegetated or because they may not understand the management effort required to sustain the ecosystem. In order to mitigate these difficulties, each restoration project should have an explicit statement of the product to be ultimately produced and the condition at intermediate stages toward the eventual goal. Criteria for determining significant deviation from these expectations should be clearly and explicitly stated. An advisory panel not deeply involved with the project must be established to review progress periodically and to determine whether the project should be scrapped. Additionally, there should always be several alternative standby plans so that if Plan A fails, Plan B can be implemented. Communicating to the general public and to the parties more directly involved that the outcome is uncertain is extremely important. It is also important to build into the original plan an alternative course of action so that those responsible for the project will not feel their professional reputations are damaged if an alternative course of action is necessary.

CONCLUDING REMARKS

The vast ecosystem damage now occurring in the world will require restorative efforts. Since global carbon dioxide is one of the problems and utilization of carbon dioxide and storage of carbon by vegetation may alleviate this problem, some of the wealthier countries should help some of the less fortunate in restoration and revegetation efforts in their own self-interest (e.g., Lovejoy, 1988). In order for these efforts to be successful at particular sites, a public awareness program similar to the one established by Janzen (1988) will be essential. It will also be essential for the various disciplines and professions to work together more effectively than they are at present.

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