SOME PROBLEMS IN ECOLOGICAL THEORY AND THEIR RELATION TO CONSERVATION

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Although the subject of my paper is a rather general one, I choose to develop it from specific case studies. Because I am more familiar with American forests than with other resources, most of the following discussion will deal with forest problems. Our university owns and operates the Harvard Forest in north central Massachusetts, and the Harvard Black Rock Forest in the Hudson Highlands of southern New York State just west of the Hudson River about 60 miles (97 km) above New York City. Most of the former, composed of about 2400 acres (1000 ha), came to the college in 1907. The latter, about 3700 acres (1500 ha), came to us in 1950, but was kept under experimental management by its former owner after 1928. The history of these two tracts of woodland, and the ideas that have evolved around them, will lead to most of the things I wish to say.

ECOLOGICAL THEORY IN FOREST MANAGEMENT AND RESEARCH

The Hudson Highlands form a range of heavily glaciated granitic hills that extends in a north-easterly direction across northern New Jersey and southern New York. Within our forest the hills rise to about 1460 ft (450 m) above the Hudson River, which is tidal here. Most of our land lies above 1000 ft (300 m), and is thus in an area characterized by rolling, often bare rock hills separated by patches of thin glacial till and colluvium.

Thirty-eight species of native deciduous trees occur in the Black Rock Forest, and five species of conifers. About fifteen deciduous trees are common and characterize nearly all of the woods. A striking feature of the forests is the difference in the form and height-growth of the trees that occurs with altitude. From the gnarled, short-boled forms on the hill-tops and high slopes there is a gradual transition to straight, tall trees in the deeper valleys. The forests of the area were first used in the early seventeenth century, chiefly for fuel-wood in small sizes. This led to repeated clear felling at intervals of 30–40 years. Only about 40 acres (16 ha) of our land were ever cleared for farming. Although there is ample rainfall, fires have been common.

The first publication from the Black Rock Forest was a bulletin issued in 1930 by its director. He stated the purpose of the institution as follows: 'The chief aim of this laboratory is the determination of which silvicultural systems should be applied to the several types here represented to bring the land to the highest possible point of sustained yield, profitable forest crop production and to so maintain it' (Tryon 1930, p. 42). Throughout the introductory pages of the bulletin (Tryon 1930) there is repeated emphasis upon the idea that the woodland was in a 'ravaged' state, that its 'reproductive capacity' was 'enfeebled', that its soil was 'impoverished'. Pejorative terms such as 'abusive methods of exploitation' were freely used, and the idea was expressed that these methods had notably altered the composition of the stands. With these views went the hopeful idea that by applying knowledge already at hand or soon to be discovered, the forest would be 'rejuvenated in growth and value and the soil restored as far as possible to its maximum fertility'.

The stated plans for research and operations at Black Rock Forest were based on a series of interlocking assumptions. These assumptions were integral parts of the American ecological theory and conservation thought of the time. They were not even mentioned in *Bulletin* 1 because they were generally accepted as truisms or sound guiding principles.

The first basic assumption was that there actually had been a more productive forest on this land prior to settlement. Embedded in this assumption was the concept of the 'forest primeval', which has played a highly significant role in all of American conservation thought. The second assumption was that this former productive forest had been destroyed, devastated and debased by western Europeans after they came to America in the seventeenth century. Then came the assumption of the biological and economic feasibility of the rehabilitation of this forest under sustained-yield management. This was a cornerstone of what Hays (1959) has called the 'gospel of efficiency' upon which American forest conservation was founded. Sustained yield rested in turn upon four other assumptions which I shall discuss later.

Because so much of American theory and concept in forest ecology and conservation has rested upon these assumptions, I shall examine them in the light of our present knowledge, using our two experimental forests as illustrative case histories.

The assumption of the pre-settlement forest

The author of *Bulletin* 1 had found a description of the pre-settlement forest of the Hudson Highlands. This description came from a paper published in 1915 by W. L. Bray on 'The development of the vegetation of New York State.'

Bray believed '... that New York was found to be a great forest region; that a vast blanket of humus material had been spread over the land, hill-top as well as valley; that upon bare rock, great boulders ... as well as broad rock surfaces, a matrix of organically rich soil had been built up so that forest trees grew upon it; ...' (p. 88). He conceived that this forest had been produced by a long period of successional and soil development, *in situ* (p. 89), and that 'it had in large measure reached a stage of stability or equilibrium in which a certain permanency of forest type is maintained ... ' (p. 20). He called this stage the 'climax' (pp. 168–73).

He wrote further that 'Under present conditions—*i.e.* through the activities of human agency—a great deal of the ... Hudson Highlands ... [has] been thrust back into the earlier stages of vegetation history. This has been brought about largely through the destruction of the humus blanket or organic cover built up by the vegetation'. He went on to say that 'despite the prevalence of xerophytic habitats, the action of vegetation had, by the beginning of the era of cultural interference, brought almost the whole of this territory into a condition of moderately constant water supply and of heavy, large growth vegetation if not of climax forest' (p. 159). To account for the existing condition of the Highland forests he proposed 'that the protective effects of forest cover—the organic soil blanket—have been so far degraded that the vegetation shows an undesirably strong tendency toward xerophytism' (p. 179).

Here, then, was the basic ecological idea used to rationalize the research and operating plans for the Black Rock Forest. An ancient, rich, more productive forest had been present when the settlers came. Its rehabilitation was a major aim of the institution for many years.

It occurred to me, when I began some studies at Black Rock Forest in 1936 (Raup 1938), that if exploitation and fire had altered the woods to so great an extent, the local geographic boundaries of compositional types ought to show a certain amount of coincidence with the outlines of felled or burned areas. Further, I thought there ought to be some physical evidence of the erosion and deposition of humus and mineral soil called for by the assumption. On the contrary, the type boundaries tended to cross the old boundaries of cutting and fire areas at random. Careful studies of humus soils in deep, cup-like valleys gave no evidence that they had ever been augmented by additions from above (Scholz 1931). The mineral soils on the steep upper slopes showed no signs of accelerated erosion except in a few places where wagon roads were made at right angles to the contours (Denny 1938). Individual old trees ranging in age up to 300 years were found throughout the forest, on all kinds of sites, from the tall, straight stands of the lower slopes to the bush-like stands of the hill-tops. Wherever found they matched the species and growth forms around them, thus suggesting that neither the types nor the sites had changed much during their lifetimes.

Then I found the earliest description of the Hudson Highlands we have, written by Robert Juet, mate on Hendrik Hudson's discovery ship, '*The Half Moon*'. While the ship was anchored for a time in what is now called Newburgh Bay, just north of the Highlands, the people aboard her could see some of the hill-tops and northerly slopes that are now part of the Black Rock Forest. Under date of 30 Sept., 1609, Juet wrote as follows (Juet 1609): 'The thirtieth was fair weather, and the wind at southeast a stiff gale between the mountains. We rode still the afternoon ... The mountains look as if some metal or mineral were in them; for the trees that grew on them were all blasted, and some of them barren with few or no trees on them.' Here is an eye-witness view of the northerly slopes and summits of the Highlands in pre-settlement time indicating that they looked about as they do now, with their bare rock, stunted forests and xerophytism.

Cases of this kind are becoming numerous in studies of American pre-settlement vegetation, but I have space for brief mention of only one other. A 'climax' forest of similar structure was described for the upland moderately drained loam soils of northern and central New England, with various forms of 'physiographic climaxes' on excessively or very poorly drained soils (Nichols 1935; Braun 1950). We now know from historical studies at the Harvard Forest that this upland climax did not exist in north central Massachusetts (Stephens 1955a, b; Raup 1954, 1957). The general disposition of species and species groupings in the landscape that we now see, as well as the form and age structure which we find in our older stands (80–130 years), are essentially those found by the first settlers who came to our area in the second quarter of the eighteenth century.

The assumption of forest devastation

The pre-settlement, rich, productive forest described with such apparent authenticity by Bray for the Hudson Highlands had lost most of its significance as a base upon which to plan the research of the Black Rock Forest. The pre-colonial woodland reconstructed for the lands of the Harvard Forest in Massachusetts also proved useless for realistic management. I hardly need say that the collapse of these reconstructions forced a reassessment of the assumption of devastation by invading Europeans in the seventeenth and eighteenth centuries, for the essential features of the devastation were already there when the first settlers arrived. Rehabilitation of the forests, in the sense formerly used, ceased to be a major aim of management. Rather, the datum plane for research and development became the existing forests.

SOME PROBLEMS IN ECOLOGICAL THEORY

Thus far I have defined some specific instances of the failure of ecological theory to function realistically when applied to the management of forests. It is proper that we should look critically at this body of theory before going on to the concept of sustained yield.

American ecology, though it was built upon the physiological ecology and plant geography of Warming and Schimper, was turned very early into studies of vegetational dynamics by Cowles and Clements, its principal founders. Cowles, greatly influenced as a young botanist at the turn of the century by the work of Davis, Salisbury and Chamberlain in the burgeoning field of geomorphology, quickly developed his 'physiographic ecology'. This involved processes of interrelated geomorphic and biologic change, but with time intervals of physical habitat stability, during which long-term successions among communities of plants could develop. Some of the successions had long-lived trees in them, and beginning with pioneers on newly formed ground, went on to relatively stable associations (climaxes) that would last until major physiographic or climatic changes slowly altered them. Clements greatly elaborated these ideas, but made no change in the essential theory. Both men emphasized the community, almost exclusively, as the basic unit for the study of vegetation.

With their ideas of community, succession and climax, supported as they were in a widely accepted physiographic framework, our plant ecologists had a formidable analytical tool. It was internally logical, and eminently teachable. The assumption was made that nearly every stand of vegetation was in some stage of development—from something that it had been to something that it was becoming. Time, in potentially large units, was built into the assumption through the concept of slow physiographic and climatic changes that permitted long periods of relative stability in the site. At the beginning of the twentieth century there was very little vegetation left on our continent which had not felt the hand of invading western European man, or was thought to have felt it. From this it could be further assumed that the white man's disturbances of the vegetation were traumatic, and the first major ones that had occurred in a very long time, perhaps in millennia.

By the free use of analogy and inference, and the arrangement of communities on gradients of varying mesophytism, long-term predictions of what each stand would become were rather easily made. A curious property of this engine of analysis was that it would run backwards as well as forwards. Because for any given region there was, *a priori*, a climax, and because this climax was self-perpetuating, its species had to be those capable of regeneration that would produce the climax. In the case of forest these were the 'tolerant' ones. Such a forest would by definition be a very old one, all-aged, and it would, in the north temperate regions, have a heavy ground cover of humus. The heavy, productive forest that was described for the Hudson Highlands in pre-settlement time was so constructed simply by projecting the theory backwards.

Plant successions are thoroughly documented, in vegetation that has been naturally or artificially disturbed. But I believe I am correct in saying that wherever old American forests dating back to pre-settlement time have been studied historically they have failed to satisfy the requirements of the self-perpetuating 'climax'. One of the most important of these requirements is that the trees shall be all-aged. However, a universal feature of our old forests is that they are even-aged or have one or more well-defined age-classes in them. This phenomenon is known in so many parts of the continent, and in so many types of forest, that we cannot ignore it. We know of no way to account for it other than by the occurrence in pre-settlement time of disturbances that destroyed or decimated whole forest stands.

Real evidence for these pre-colonial disturbances is now accumulating. In much of eastern United States and eastern Canada wind has been a major disturbing factor (Stephens 1955a, b; Goodlett 1954; Raup 1954; Denny & Goodlett 1956). Its importance in the north-west coastal region is indicated by the forest destruction resulting from the great storm of 12 Oct. 1962. Wherever coniferous trees form a large part of the North American forests, fire has been the principal cause of disturbance (Lutz 1956, 1959). Malin (1956) has described the influences that kept our grasslands in a disturbed state for countless years before the coming of the fur traders and settlers.

Thus there was fundamental instability in the site; and here at the base of our ecological theory was a serious flaw, for many sites were assumed to remain relatively stable over long periods of time. The prevalence of even-ageing by stands or age-classes in the pre-settlement forests indicates that the frequency of the disturbances has been great enough to preclude all but fragmentary successions whose dimensions have been indeterminate. Furthermore, the proportional species content and basic structure of the vegetation of an area at any point in time has been more likely the product of the last major disturbance than of necessary relationships within a community.

I propose that the vegetation under these circumstances be conceived of as an open system, and that its behaviour is a function of the behaviour of the species or ecotypes that were available to it as it emerged from the last major disturbance of its habitat. Our understanding of it will depend upon our knowledge and interpretation of the history, geographic distribution and tolerance of the species, projected against site complexes in which we can see some order along gradients in space at points in time. Understanding of its behaviour over time, as well as much of its present condition, will depend upon how well we can analyse such indeterminate fragments of development as we can see projected against the uncalibrated uncertainty of the site as a whole.

THE CONCEPT OF SUSTAINED YIELD

At the beginning of this century Gifford Pinchot stated for American consumption the concept of sustained yield in forest practice (1899). He derived this concept almost entirely from the forestry experience of western Europe.

I have already suggested that the effective operation of sustained yield rests upon four basic assumptions (Gould 1962), all of which appeared to be valid in Europe when Pinchot stated the principle for Americans. The first of the assumptions is that forest products in the economy in which the operation functions are so scarce that land can most profitably be used intensively to produce them. The second is that this economy will require a stable and regular flow of wood from the forest. The third assumption says that knowledge of production and consumption patterns is adequate for planning forest production five to ten decades ahead. Finally it is assumed that the forest operating unit, region, or nation is best served by equating internal production and consumption, and by disregarding opportunities for supply from outside, or for alternative uses of its own capital resources. Gould (1962) expressed these four assumptions in simple terms, respectively, as scarcity, stability, certainty, and a closed economy.

Three of these assumptions resemble ecological concepts that I have already discussed, and which were found wanting in actual application. One was the idea of habitat stability over long periods of time, giving rise to a degree of certainty as to the course of development over time. The closed economy has its counterpart in the concept of the selfsufficient climax. The assumption of scarcity has no readily perceivable analogue in ecological theory.

I cannot spell out the results of sustained-yield management at the Black Rock Forest because data for it are inadequate. I can, however, do so for the Harvard Forest in Massachusetts over a period of 50 years (Gould 1960).

The Harvard Forest started its operations in 1908 on about 1600 acres (650 ha) of land which were soon increased to about 2200 acres (890 ha). At the beginning it had about 12 million board feet of merchantable sawtimber, 90% of which was in white pine. Income from the sale of wood products over the years was to pay the cost of all operations, plus a profit. The trees were to be regarded as capital. The rate of annual increment in the forest was calculated, and the annual cut was to be kept within this amount. Regeneration of the cut-over areas was to provide for capital renewal.

It soon became obvious that the white pine could not be reproduced economically on the upland loam soils, where most of the Forest was situated. This would eventually have forced a recalculation of projected yields, for the pine was succeeded by slower-growing hardwoods. The total inventory, however, was held at about 12 million feet until 1922. Between 1922 and 1938, due in part to over-optimistic growth estimates during this period, and in part to over-cutting because of falling prices, the inventory was reduced to about 9 million feet. This could have been corrected in a few years; but before it could be done the hurricane of 1938 eliminated 6 million board feet of the capital inventory. The hurricane was so widespread that markets were glutted and the income from salvage sales barely paid for the operations. At the end of half a century the Harvard Forest, as a demonstration of sustained yield, was a sorry spectacle. It had almost no annual income, and it had lost two-thirds of its capital, due almost entirely to external causes over which it had no control, and which had been unpredictable.

The assumption of scarcity

The attention of the American public was focused upon its forest resource at the end of the nineteenth century, and its energies marshalled, largely through the efforts of a few young men, among whom, as I have said, Gifford Pinchot was most prominent. These men succeeded in convincing the public at large that our nation was threatened with a serious shortage of wood. They produced evidence to prove that within 50 years vast areas of our country would become barren.

In the last half century our population has doubled and our gross national product has quadrupled. Lumber use in this period has just held its own. About 6½ billion cubic feet were used in 1900, and almost the same amount in 1950. In thirty of the intervening years less were used. Total industrial wood consumption had increased only 15% by 1950. From 4% of the gross national product in 1900, wood products have fallen to less than 1%. Our *Timber Resources Review*, published by the U.S. Forest Service in 1958, could make predictions of shortages only in certain better grades of sawtimber, and could make them valid only for the year 2000, which is beyond the planning horizon of most of our wood-using industry. Of wood in other forms we are growing more than we are using or have any real plans for using. In sober fact there was not, nor has there ever been in America, a shortage of wood, or of land on which to produce wood (*cf.* Callahan 1962).

The assumption of stability

The Harvard Forest needed a steady income. The sustained-yield concept held that the economy would demand a regular flow of wood products from the Forest. This proved a myth. Both demand and prices fluctuated wildly from year to year. There was alternating feast and famine, with extreme low points in the depression years and after the hurricane.

The assumption of certainty

Production schedules at the Forest in the past five decades were uncertain enough, but consumption schedules were even less predictable. The markets of 40 years ago have virtually disappeared, and have not been replaced. Technological developments in the use of wood and wood substitutes, and in the use of forest land for purposes other than the production of wood, have been unprecedented in the last few decades. Under these conditions any assumption of certainty about future demands and values in long-term planning becomes highly suspect. It looks as though a better assumption would be that predictions beyond one or two decades were more likely to be wrong than right (Gould 1960, 1962).

The importance of short-term planning horizons has been greatly accentuated in recent years by the sudden rise in the use of forest land for recreation and living space. The values which these uses are inserting into all calculations for the future of the land are new, imponderable, and changing at a rapid rate. It is difficult to find, in American writings prior to the middle third of the nineteenth century, descriptions of the forest as a thing of beauty or as something worth preserving. A few authors such as George Perkins Marsh (1864) and George B. Emerson (1846) began to interpret the treatment of the forest by the settlers as *wasteful*. This idea gained ground slowly, and came to full flower in the early 1900s with the conservation movement. The devastation of American forests by the settlers, and by the loggers who accompanied or preceded them, became a major theme in this movement (Pinchot *et al.* 1919).

It seems clear that the roots of this theme were not solely in aesthetic appreciation of forested landscapes, but rather were an amalgam of aesthetics and a public consciousness of the social costs that had arisen in the aftermath of the great logging operations. There is no question that some of our lands were badly damaged, particularly those with erodible soils in the south, and locally elsewhere. But it is equally clear that most of our lands have never been devastated to anything like the extent they were believed to be 40 years ago. The conservation movement focused public attention upon the supposed devastation of our virgin forests just as our ecologists were coming forward with their theories of long-term succession and climax. These theories enabled the foresters and conservationists to assemble precise images of what was believed to be lost. These images were of great value to the conservation movement, for they not only set scientifically determined goals for the foresters, but also they were filled with aesthetic values and nostalgic overtones. They motivated much of the movement, and at the same time clouded it.

The assumption of a closed economy

The economy of the Harvard Forest proved to be at the mercy of powerful influences from beyond its borders. It was continually responding to new knowledge, and to rapid technological innovation on a wide variety of fronts—in transportation, industry, marketing, the utilization of new raw materials, and in experiments with new institutional structures. It seemed to be operating in an open system, as did the forest as a biological entity. With wood so abundant and cheap, the opportunity for gain by manipulating, not the forest but the capital it represented, was always present and attractive. At any time during its first 50 years the Forest could have liquidated its wood capital and invested the proceeds with the Treasurer of the University. Had it done this in the early 'twenties, when stumpage prices were relatively high, its net return at the end of the 50 year period would have been nearly ten times what it actually was, even calculating at simple interest, and its capital value would be eight times greater than it now is (Gould 1960).

ECOLOGY AND THE RESOURCE PROBLEM

Ecological and conservation thought at the turn of the century was nearly all in what might be called closed systems of one kind or another. In all of them some kind of balance or near balance was to be achieved. The geologists had their peneplains; the ecologists visualized a self-perpetuating climax; the soil scientists proposed a thoroughly mature soil profile, which eventually would lose all trace of its geological origin and become a sort of balanced organism in itself. It seems to me that social Darwinism, and the entirely competitive models that were constructed for society by the economists of the nineteenth century were all based upon a slow development towards some kind of social equilibrium. I believe there is evidence in all of these fields that the systems are open, not closed, and that probably there is no consistent trend towards balance. Rather, in the present state of our knowledge and ability to rationalize, we should think in terms of massive uncertainty, flexibility and adjustability.

Traditional emphasis in American conservation has been upon expected physical scarcity in our natural resources. We borrowed this from the Old World, forgetful that it had little meaning in the midst of our abundance. More important, we were caught in systems of thought that did not allow for uncertainty, and for the unpredictable effects of innovation throughout the whole society that would use the resources. Our experience with forests, for example, has made us acutely conscious of the preference for capital management over land and forest management. There is increasing evidence that this preference applies in other resource areas as well (Brinser 1962). I can suggest only an outline of the way in which ecological theory, as I have tried to recast it, might relate to the resource problem.

When a resource is foreseeably in abundant supply, capital investment to increase the supply will not flow. On the other hand, when the resource is scarce, decisions will be made to invest capital for its increase, or to produce substitutes for it. Technological innovation in the use of, and substitution for, natural resources now goes forward rapidly, and the society in which this process operates is evolving its institutions along with its technologies. Our experience of the last half century suggests that prediction of demand for the resources beyond one or two decades can have no precision. When I use the term 'scarce' I propose that it will apply to all kinds of values, tangible or intangible.

There is a strong economic flavour in the views I have just expressed. It is necessary to recognize some fundamental weaknesses in them. They carry an assumption that we are dealing with measurable quantities, when this is only partially true. Further, they assume that production schedules for natural resources are all equally well known, which is far from the truth. We are conditioned to think that the only measures of value which have much precision are those that come from the market place, but we find ourselves dealing with a vast array of resource values that do not go through the markets.

With our capacities to predict severely limited by inadequate measuring devices, by lack of knowledge of the resources themselves, and by the rapidity of innovation, it is probably reasonable to strive for efficiency in resource management only in the short run. Uncertainties in the long run call for the greatest possible flexibility in resource use. It is commonly assumed that these two objectives are incompatible, but I think we have reason to believe that they are not so in all cases.

Our natural vegetation in America, even before the coming of Europeans, seems to have lived in a continuing state of major readjustment. Its history of disaster had atomized it, and this I conceive to be one of the greatest blessings we received when we inherited it. In our material resource affluence, one of our largest problems is to spread the opportunity for gain and the risk of loss over many kinds and conditions of resources. This need is made essential by the constantly changing demands for the resources. The natural vegetation, as we found it, was ideally conditioned for manipulation and use in this pattern. Because of its abundance and atomization, both in kind and condition, it is adjustable to remarkably short-term planning so long as we do not attempt to achieve stability or uniformity in it.

I propose that we should plan ahead only so far as we can see with some degree of precision, and then readjust our plans at frequent intervals. We can be assured that there will never be enough facts available to give these plans any finality, and that we shall always be making judgments based upon probabilities. At every point of decision we will make use of whatever knowledge and measurement of value we can acquire, testing each for relevance to the point at issue as it relates to the frame of reference existing at the time. What we do with our capital or with our natural resources will rest upon these decisions.

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