diverges with sufficient rapidity, then the one-dimensional model will exhibit condensation without the artifact of an extra limiting process ($\gamma \rightarrow 0$).

These models are realistic insofar as we use more or less realistic interactions and fundamental inasmuch as we follow the strict dicta of statistical mechanics. They are conceptual and ad hoc, because, after all, there are no one-dimensional gases. Still, the study of such models has been most profitable, especially since it throws considerable light on the *mathematical mechanisms* which may be responsible for the phenomenon of condensation.

Conclusion

Models are, for the most part, caricatures of reality, but if they are good, then, like good caricatures, they portray, though perhaps in distorted manner, some of the features of the real world.

The main role of models is not so much to explain and to predict—though ultimately these are the main functions of science—as to polarize thinking and to pose sharp questions. Above all, they are fun to invent and to play with, and they have a peculiar life of their own. The "survival of the fittest" applies to models even more than it does to living creatures. They should not, however, be allowed to multiply indiscriminately without real necessity or real purpose.

Unless, of course, we all follow the dictum, attributed to Oswald Avery, that "you can blow all the bubbles you want to provided *you* are the one who pricks them."

References and Notes

1. It is interesting to note that, both in the case of atoms and in the case of genes, the underlying "discrete structure" was suggested by the appearance of definite ratios. This contrasts sharply with the origin of definite ratios of frequencies of tones of a string or a drum, or, for that matter, of energy levels of an atom. Here the underlying structure is continuous, as described by differential equations, and the discrete spectra arise because these equations have nontrivial solutions only if a certain parameter belongs to a discrete set of values.
2. See C. J. Thompson, *Biopolymers* **6**, 1101 (1968). Here one finds, also, references to Monod, Wyman, and Changeux and to Koshlund *et al.*
3. Since $P + Q = 1$ and $Q/P = \hat{L}$, the formula becomes

$$f = \frac{1}{1+\hat{L}} \quad \frac{\alpha}{1+2} + \frac{\hat{L}}{1+\hat{L}} \quad \frac{c\alpha}{1+c\alpha}$$

4. The theory of the "ideal observer," as well as a discussion of some of the experiments performed at the Radiation Laboratory during World War II, can be found in *Threshold Signals*, J. L. Lawson and G. E. Uhlenbeck, Eds. (McGraw-Hill, New York, 1950) (M.I.T. Radiation Laboratory Series, vol. 24). The theory is an adaptation of the Neyman-Pearson ideas relating to the testing of hypotheses.
5. See M. Kac, *IRE (Inst. Radio Engrs.) Trans. Profess. Group Inform. Theory* **IT-8**, 126 (Feb. 1962).
6. See, for example, J. A. Swets, *Signal Detection and Recognition by Human Observers* (Wiley, New York, 1964). I am grateful to R. W. Taylor of the Advanced Research Projects Agency for calling my attention to this reference.
7. For a more complete discussion see, for example, M. Kac, *Probability and Related Topics in Physical Sciences* (Interscience, New York, 1959).
8. M. Kac, G. E. Uhlenbeck, P. C. Hemmer, *J. Math. Phys.* **4**, 216 (1963).
9. F. J. Dyson, in preparation.

Aquatic Weeds

The rampant quality of aquatic weeds has become one of the symptoms of our failure to manage our resources.

L. G. Holm, L. W. Weldon, and R. D. Blackburn

In the evolution of the city as a habitat, in the conversion of virgin lands to intensified farming, and in the alteration of watercourses with locks, dams, and reservoirs, man is the interloper. At his behest the natural order of things is set aside. As a result of his activities and their byproducts, new species and numbers of weeds, rodents, insects, and diseases appear where they could not, or did not, exist before. One of our priceless treasures, fresh water, is changed as civilization draws near. Its quality usually becomes poorer; it is seldom improved by man. Communities, planned and unplanned, locate on the water's edge to use navigation routes, irrigate land, and develop power. As a result the watercourses are heated, polluted, and fertilized; the levels fluctuate, and new biological pests are introduced because of man's commerce and mobility.

Several "explosions" of aquatic weeds in the great rivers and lakes of the warm regions of the world have forced us to recognize the power of such infestations. They destroy fisheries, interfere with hydroelectric and irrigation schemes, stop navigation, and bring starvation and disease problems to riverine communities. The rapid growth of weed infestations has been both spectacular and frightening, and the publicity devoted to several of these problems in the past decade has made us aware that something is wrong.

Aquatic weeds obstruct water flow, increase evaporation, cause large losses of water through transpiration, and prevent proper drainage of land. Weeds may interfere with navigation, prevent fishing and recreation, depress real estate values, and present health hazards. In the western United States, Timmons (*1*) showed that 17 states lost 1,966,000 acre-feet of irrigation water annually because of aquatic and ditchbank weeds. This water, valued conservatively at \$20 per acre-foot, is worth \$39,230,000 (*2*). This is enough water to irrigate 132,000 to 315,000 hectares of cropland. In the United States there never has been an evaluation of the total nonagricultural losses due to aquatic weeds. It is certain that this loss, too, would be very high.

The aquatic environment is complex and is of interest to scientists in several disciplines. The management of aquatic vegetation is not a new science, but rather an old field of botany that has been recently revitalized because of increased demand on our fresh waters and the exponential growth in problems caused by aquatic vegetation.

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Water Hyacinth

The scourge of some of the world's major rivers is water hyacinth, *Eichhornia crassipes* (Mart.) Solms in the family *Pontederiaceae* (Fig. 1). A native of South America, it is now widely distributed over the warm regions of the earth (Fig. 2). The plant is free-floating, has very fine roots, and produces stolons and viable seeds. The leaves are 10 to 15 cm across, bright green, shiny, and, because they are upright, serve as sails before the wind. The lovely flowers are pale lilac or mauve with a yellow patch at the center. Because of his admiration for the flowers, man has assisted the spread of this plant by cultivating it in his pools and gardens. His carelessness toward the cleanliness of his commercial and pleasure craft on land and sea has also contributed to the movement of the plant. For example, charcoal is made in the bush in Africa; and holes in the sacks used for transport are sometimes plugged with water hyacinth plants that may survive a very long journey. Large plants are used as cushions for sitting and kneeling in native canoes, to be thrown away at any place where the plant ceases to be useful. The plants catch on the sides and bottoms of river craft and thus move with the commerce of the region. Natural forces and events have also been important in the spread of water hyacinth. From the nurseries in the swamps and backwaters, great islands of the weed are flushed into the mainstream at flood time.

Water hyacinth populations increase rapidly by vegetative reproduction. In one experiment two parent plants produced 30 offspring after 23 days, and 1200 at the end of 4 months. A plant may flower at the age of 26 days and will normally produce viable seeds. Seed production varies from a few to as many as 5000 seeds per plant. The seeds sink to the bottom and may remain viable for at least 15 years. Movement of seeds between watercourses must surely take place in the mud on furbearing animals and on the legs of birds. Recent reports of the long-distance dispersal of seed by waterfowl and shore birds suggest a possibility that has never been taken seriously. These migrating birds can carry seed several thousand kilometers in one season (*3*). In the face of such vectors, once the seed of a species is on a continent, there may be little that man can do to prevent its spread.

Fig. 1. The flowers of water hyacinth *Eichhornia crassipes* (Mart.) Solms.

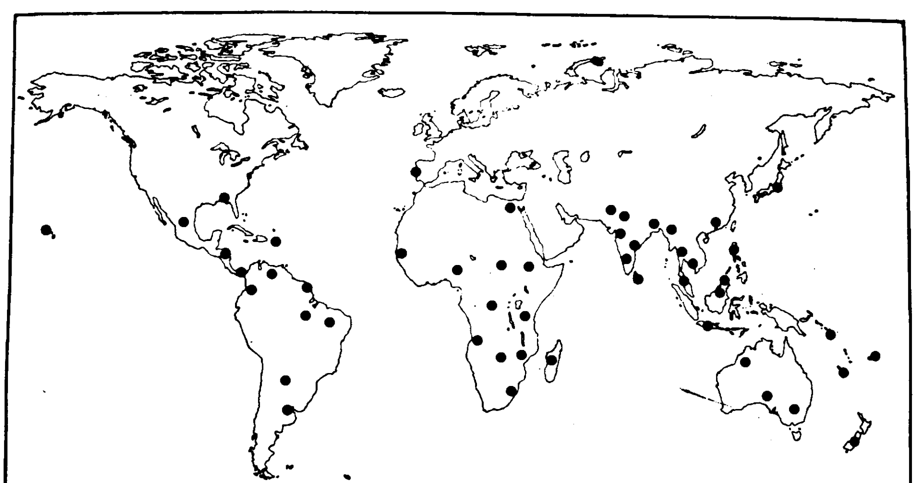

Fig. 2. The distribution of water hyacinth.

An account of the spread of water hyacinth in the Congo and Nile rivers will illustrate the immensity of the task we face. The species had been introduced at the delta of the Nile and in Natal, South Africa, at the beginning of the century. Europeans who settled in South Rhodesia in 1937 reported the presence of water hyacinth. It is now generally distributed in Africa. In spite of the losses and human suffering caused by this plant, it was still available in 1965 for purchase as an ornamental in the street markets of Senegal. In the United States, federal law prohibits interstate shipment of water hyacinth, but it is offered for sale in the catalogs of many distributors of water garden plants.

Water hyacinth was first reported in the Congo River in 1952 and in less than 3 years it had spread 1600 kilometers from Leopoldville up to Stanleyville. In 1954 it had already begun to block transportation. Buoys were submerged and navigation channels were hidden. Fish spawning areas were blocked. Many fishing grounds were destroyed by darkness and lack of oxygen as the weed cover became more dense, and, as a result, the riverine communities were denied their principle source of protein. Using herbicides applied from ships, planes, and helicopters, by 1957 Belgian scientists had directed the cleanup of more than 1600 kilometers of the river at a cost of $1,000,000. In spite of this massive effort, Le Brun reports that in the same year water hyacinth was still floating past Leopoldville on the way to the sea at the rate of 136 metric tons per hour (*4*). During the turbulent years following independence, the Congo government services could not maintain the weed control program, and the Congo River is again badly infested.

The history of the infestation of the upper White Nile is equally tragic. The first report of the weed in the White Nile was in 1958. Again, the multiplication and spread took place so quickly that even the best efforts of the Sudan government could not organize a campaign in time to contain the weed. A staff of 200 workers equipped with ships, planes, and land vehicles was organized to keep the river and the harbors open. During the early 1960's, the water hyacinth team of Sudan was able to keep the weed under control in the most critical areas with herbicides. At one time the cost of this operation was $1.5 million per year (5).

In addition to all of the usual hardships caused by the weed, men now began to see the impact of its uncontrolled growth on clogged irrigation pumps and hydroelectric schemes. Some river villages that were regularly supplied with food by boat began to starve because they could not be reached. Insect vectors of human and animal diseases seek harbor in the mats of water hyacinth; so do dangerous snakes and crocodiles. In recent years the political difficulties in the south of the country have prevented workers from spraying many of the nurseries and sources of infestation in the upper White Nile. The region is again in serious difficulty. Figures 3 and 4 depict the change that took place between 1958 and 1965 above the dam at Jebel Aulia on the White Nile near Khartoum.

The people of Sudan deserve much credit for preventing the spread of water hyacinth from the White to the Blue Nile. The confluence of the two rivers is at Khartoum, and above this point a quarantine system, including many vehicle checkpoints, has been organized and is efficiently administered. By preventing the spread of the weed from the White to the Blue Nile, the Sudanese have protected the great irrigated Gezira cotton scheme.

Water hyacinth is present in the sloughs and backwaters of the Amazon River. It seldom appears to be a problem in the Amazon, perhaps due to lesser demands on utilization of this waterway, or to the presence of natural factors such as insects or plant diseases that limit growth of the weed. It does interfere with man's activities in many lakes, streams, and reservoirs of Central and South America. Many large reservoirs such as Brokopondo in Surinam, Lake Apanas in Nicaragua, and Lake Rio Lempa in El Salvador are threatened with economic disaster if dense stands of water hyacinth are allowed to develop.

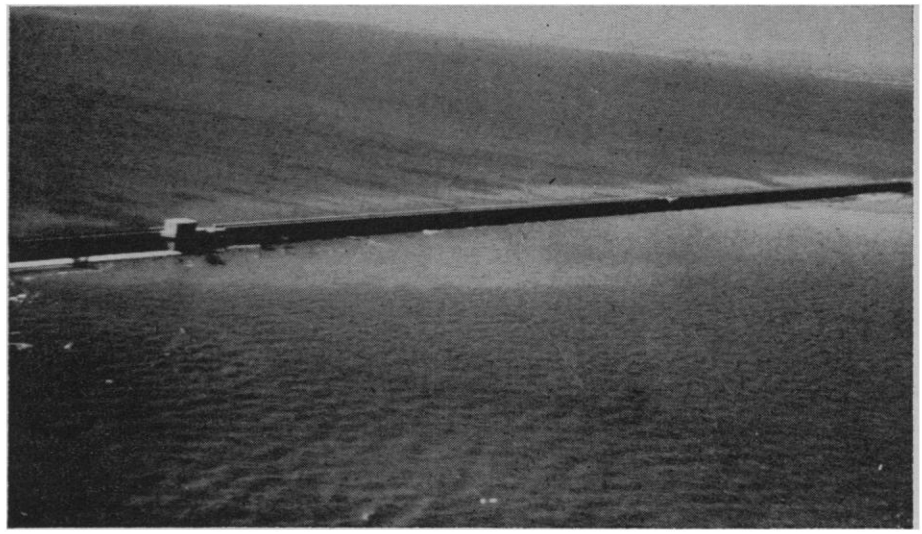

Fig. 3. The dam on the White Nile at Jebel Aulia near Khartoum, Sudan. The area was clean when photographed in October 1958. [Courtesy E. Buyckx]

The benefit of these reservoirs is dependent upon the amount of available water. However, water hyacinth consumes and wastes tremendous quantities of water through the leaves. The loss of water through evapotranspiration from the leaves has been measured as 3.2 to 3.7 times greater than free evaporation from a surface. This accounted for a loss of more than 6 acre-feet of water in a 6-month period due to a water hyacinth cover. In the dry atmosphere of India, the loss of water through water hyacinth was 7.8 times that of open water (6). Only a partial coverage of water hyacinth on a reservoir can result in the entire river inflow being wasted back into the atmosphere. Thus, the water is not available for hydroelectric power and irrigation.

Water hyacinth is distributed generally in Asia where it may be found in India, throughout the countries of Southeast Asia, and in the Philippine Islands.

Fig. 4. The same area seen in Fig. 3, showing the accumulation of water hyacinth above the dam in October 1965.

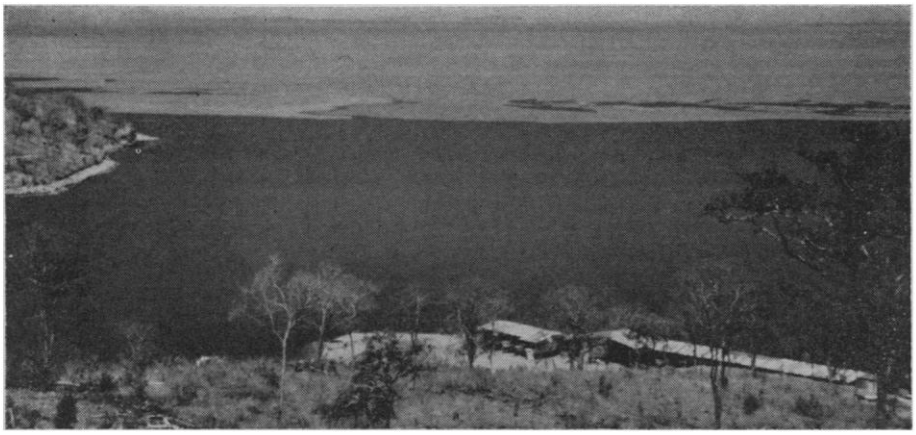

Fig. 5. A harbor on Lake Kariba completely choked with *Salvinia*. Only very powerful boats can penetrate the mat of weeds (photo taken October 1965).

In East Pakistan some of the farming areas are covered with massive deposits of water hyacinth as the floods come down from the hills in the rainy season. The weed is in Australia and New Zealand as well.

Water hyacinth was reportedly introduced into the United States in 1884 as part of a horticultural exhibit. It spread rapidly and by 1897 was creating enough havoc to navigation to prompt an investigation. Funds for control of the weed became available in 1899. A number of mechanical removal procedures were used initially to control the water hyacinth, but these have largely been replaced with herbicide programs because of the great saving in time and money. Intensive control programs are being conducted by federal, state, and local agencies, drainage districts, and private interests. In spite of this large combined effort water hyacinth caused an annual loss of almost $43,000,000 in Florida, Alabama, Mississippi, and Louisiana in 1956. The types of losses are similar throughout the world (*7*).

We have indicated some of the navigational problems in Africa. The navigation of rivers and waterways in the southern United States would be just as difficult without proper control of the water hyacinth. Many rivers have to be closed to boat traffic periodically if effective control procedures have not been followed. Fishing camps and marinas are often closed, and many are forced into bankruptcy by inaccessibility.

A cover of water hyacinth on canals with a cross section of 36 to 72 centares may reduce the flow of water by half. The flow in smaller laterals and farm ditches may be almost completely stopped. Many canal systems have to be enlarged 50 percent or more to compensate for retarded flow. An additional problem is the constant accumulation of debris from decaying water hyacinth on the canal bottom. During periods of active growth, the lower leaves and roots of water hyacinth are constantly decaying and being replaced. This debris that falls to the canal bottom may amount to more than 30 centimeters per year. If the extensive water hyacinth cover is not prevented, mechanical removal of the debris becomes necessary—at a cost of $400 to $640 per kilometer (*6*, *8*).

Salvinia

Some of the man-made lakes constructed in this century are so large that they are included on world maps. Lake Kariba, on the Zambesi River in Southern Africa, is an interesting example of the frustration which comes with massive efforts to arrange great alterations in the environment. The relocation of 50,000 people to make way for this lake caused considerable human suffering. The biological consequence of impounding such a large stream is in part illustrated by the story of the weed problem that later developed.

The Kariba Dam was closed late in 1958. The maximum water level was reached in July 1963, 4½ years later. Lake Kariba now covers more than 4200 square kilometers, has a maximum depth of 115 meters, and extends up to the foot of beautiful Victoria Falls.

In May 1959, floating mats of the water fern, *Salvinia auriculata* Aublet, were reported in the center of the lake. The mats grew in size and moved about with the wind. Before the end of the year a significant portion of the water near the shore was covered with *Salvinia* plants, as they lodged in branches of partially submerged trees and continued to multiply. By this time, *Pistia stratiotes* L. was associating with *Salvinia* in some of the mats. During 1960, less than 2 years after the dam was closed, it was estimated that the rafts of *Salvinia* had covered 420 square kilo-

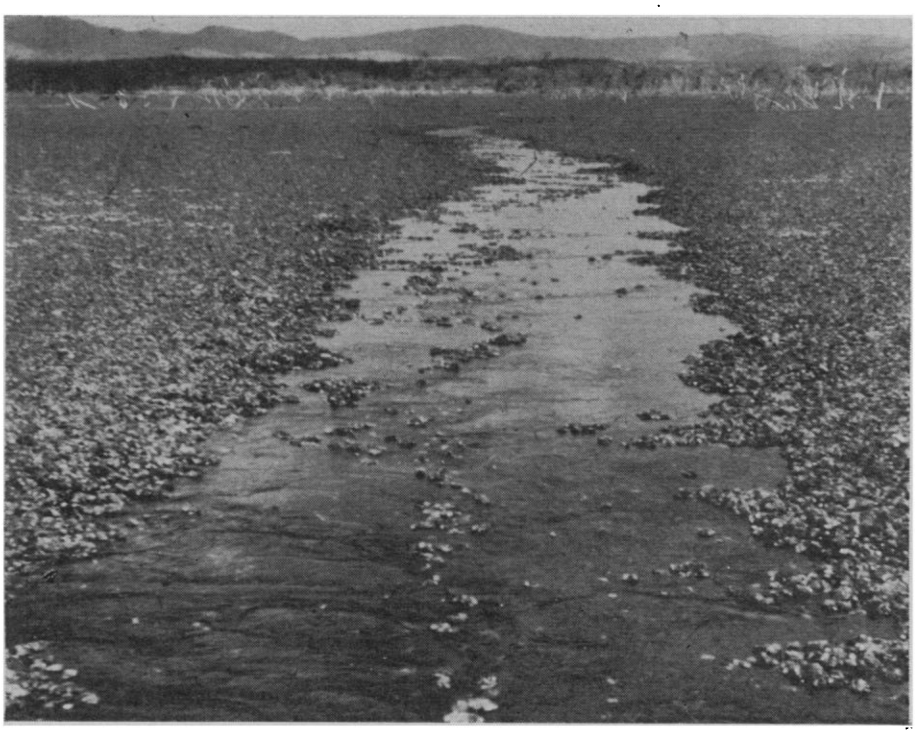

Fig. 6. A permanent mat of *Salvinia* in a bay of Lake Kariba. The weed mat closes in the wake of boats and ships which try to enter.

meters or 10 percent of the surface area (*9*). By 1965 the infestation had subsided slightly but was still estimated at 8 percent of the lake's surface (Figs. 5 and 6).

The water fern has floating leaves 3 cm long and submerged leaves so finely divided that they have a feathery appearance. In some areas the plant produces spores when it is crowded, but until 1965 only vegetative reproduction had been observed on Lake Kariba. Before formation of the lake, large infestations of *Salvinia* were present in the Upper Zambesi where they sometimes interfered with the fishing of the local people. The weed was also far up the Chobe River, a tributary which feeds into the Zambesi above Victoria Falls. In 1949, Dr. O. West collected *Salvinia* just a short way above Victoria Falls. Boughey (*9*) assumed that the weed was already present in that portion of the Zambesi River which was flooded by the lake. The records show that warnings were given about the potential weed problem at the time the lake was being planned. Not until 1960 and 1961 were serious research efforts made toward control measures that would be feasible and safe for the lake (*10*). As a result of political turmoil in the area, no important measures for control or eradication have ever been taken.

Salvinia auriculata, first described as from Guiana, has spread over a wide area in Central and South America, from Cuba to Argentina. It is known to be in the Cape area of South Africa, in the Congo River and the Cameroons on the West Coast, and in some of the countries of Southeast Asia. It first "exploded" and became a serious problem in Ceylon in the period before 1955 (*11*). At that time *Salvinia* had covered an estimated 8800 hectares of rice fields and 800 hectares of canals and other waterways within about 12 years.

Could the disaster at Lake Kariba have been avoided? The infestations of *Salvinia* in Ceylon were well known. Scheduled inspections of the shore line where weeds build up and prompt treatment of early infestations seem the only way to prevent massive explosions of vegetation which may by then be too expensive or too dangerous to treat. When man-made lakes are constructed, vegetation management must be integrated with the work of all bureaus and agencies concerned with maintenance of the watershed, the lake, and the dam. Recently, an infestation of *Salvinia* was found on Lake Naivasha in Kenya, and it was dealt with promptly and effectively with herbicides applied from aircraft and boats. Constant vigilance has kept the weed under control.

Water Lettuce

Lake Volta in Ghana deserves special mention. The dam was closed in 1964. When filling is completed, the lake will cover 8125 square kilometers. It will be the largest man-made lake in the world. By 1965 great rafts of water lettuce, *Pistia stratiotes*, some many kilometers long, could be seen floating on the surface. Extensive fringes of the weed covered scores of kilometers of the lake's edge and filled the inlets of small rivers entering the lake.

Water lettuce, very widely distributed in the world, is one of the free-floating aquatic plants that must be viewed with concern. It has pale green leaves which are broad and softly pubescent on both sides. The leaves occur in rosettes, beneath which are long fibrous roots, and the plants are connected by stolons. There is a tendency to overlook the potential danger from water lettuce on large water bodies such as Lake Volta because, presumably, it cannot tolerate action from large waves.

The most important problem caused by water lettuce is that of disease and the nuisance associated with mosquitoes. Water lettuce serves as a preferred host site for larvae of several species of mosquitoes. One or more of these species of mosquitoes serve as principal vectors of each of several forms of encephalomyelitis and of rural filariasis. The *Mansonia* larvae obtain their oxygen directly from the roots of water lettuce and never surface. The only way to control these mosquitoes is to remove water lettuce (*12*).

In an interesting experiment in which herbicides were used to destroy a 120-hectare infestation of water lettuce, there was also complete control of *Mansonia* mosquitoes for 4 months. Only an occasional mosquito of this species was trapped in the year following treatment (*13*). Demonstrations such as this suggest that suitable methods of destroying water lettuce may provide a means of controlling diseases that affect large numbers of people.

All of the foregoing species of plants are free-floating. There are many more, but perhaps the ones that deserve special mention are those of the duckweed family Lemnaceae L. A single frond may be the size of a pinhead, and there are no stems or true leaves. Members of this family propagate vegetatively by producing new individuals at the edge of the frond. They can cover the surface of an entire pond in a few weeks. Duckweeds are a nuisance in rice fields and cause trouble in irrigation systems by entering siphon tubes and pumps and by collecting on trash-racks.

The free-floating species have drawn much attention if only because massive infestations are spectacular and also frightening when they begin to move. But these are by no means the most difficult of the aquatic weed problems.

Submersed Weeds

Submersed weeds are perhaps the most serious of all aquatic weed problems, because they cannot readily be sprayed with herbicides and do not easily lend themselves to clearance by machines. Herbicidal treatments must be made to the entire volume of water, depending upon sorption of the chemical by the undesirable species to achieve control. It must be obvious that the submersed weeds drastically reduce the rate of water flow. It is as though the water must pass through an infinite series of inverted combs that create friction and turbulence.

Of all aquatics, submersed weeds cause the greatest problems in the United States. The most troublesome in the west and north are the genera *Potamogeton* and *Elodea,* and in the east include these genera and *Myriophyllum.* In the south, *Najas* and *Ceratophyllum* are the most common. In addition to these, *Egeria* is widespread throughout the United States. The filamentous and branched algae are almost always present. Also present in the United States, but important on a world basis as well, are members of the genera *Ranunculus, Vallisneria,* and *Utricularia.*

Submersed weeds also have a history of rapid invasion of new sites. Many of the waterways of Europe were blocked by *Elodea canadensis* when it was introduced in the 18th century. One of the most alarming plant invaders is eurasian watermilfoil, *Myriophyllum spicatum* L. The plant, apparently in the United States since the 19th century, has become a problem only during the past 10 years. In that period it has

Fig. 7. A flood control canal 80 feet wide and 22 feet deep completely filled with *Hydrilla* retarded flow by 90 percent.

invaded more than 80,000 hectares in the Chesapeake Bay, 2,000 hectares in the Tennessee Valley Authority reservoirs, and 26,800 hectares in Currituck Sound.

The weed causes large losses in commercial fishing, smothers shellfish beds, hinders navigation, depresses real estate values, interferes with recreational use, provides mosquito breeding sites, and clogs water intake systems. This is a perennial submersed plant that spreads very rapidly by vegetative reproduction and probably by seed. The leaves are finely dissected, and the flowering spike, without leaves, may extend 10 centimeters above the water. The plant can tolerate salinities up to as much as one-third that of seawater and can thus invade most fresh and estuarine waters. Large acreages in the TVA reservoirs have been treated with 2,4-D (2,4-dichlorophenoxyacetic acid). The chemical has been safely applied at rates of 22 to 44 kilograms per hectare. The results have varied from excellent control in protected embayments to poor control in moving water in these impoundments. The varied results of this work and the inadequacy of the control methods indicate the lack of knowledge to cope with the problem. The need is for concerned public agencies to contain new troublesome plants wherever they are first reported. In one area of Florida, eurasian watermilfoil spread from 80 to 1200 hectares in 2 years; there was no attempt to control the plant or limit it to the infested area (*14*).

The story of the invasion by eurasian watermilfoil is still another example of a species that multiplied rapidly after having been in a certain area for a long time. We do not know whether plant material was moved to a more favorable environment, or whether the habitat was altered to make it more suitable for the spread and growth of plants already present.

Submersed weeds are a menace to irrigation systems. Thousands of freshwater reservoirs, large and small, have been constructed throughout the world in the past two decades, and with them have come large new irrigation schemes. Several of these command more than 400,000 hectares. India, for example, the leading producer of three of the world's major crops, has more kilometers of irrigation canals than any other country. As people occupy and farm the land, the effluent from villages, barns, and animal yards, together with the runoff of fertilizers added to the fields, enriches the waters of the canals and reservoirs. Because the distributaries are often shallow, clear, and slow-moving, the added nutrients ensure the growth of weeds. When the weeds enter the system, water can no longer move at the design rate of flow, with the result that the fields most distant from the reservoir cannot be irrigated on schedule. The reduced rate of flow also encourages seepage from canals, and the losses from evaporation are significantly increased. These are matters for serious concern, because they directly affect food production in an already hungry world. The management of aquatic vegetation for an entire irrigation system may be the most complex of all water weed problems. These include reserves of water held in rivers, ponds, and lakes, a network of canals, and a drainage system. Frequently, the water is used for men, animals, and crops.

It is estimated that over a million additional hectares of arable land will be placed under irrigation before the end of the century. One example may serve to illustrate the futility of planning irrigation systems without, at the same time, making preparations to protect them from aquatic weeds. In one of the countries of Asia, an irrigation scheme with a command area of 560,000 hectares was completed in this dec-

Fig. 8. This $900,000 resort motel and marina was built on the banks of a crystal-clear river famous for fishing and scuba diving. An invasion of *Hydrilla* prevented the use of the waterway and forced the motel into bankruptcy 18 months after opening.

ade. One main arm of the canal system is 400 kilometers long and, with its distributaries, totals more than 1600 kilometers. The discharge at the head is equal to that of the Seine River as it flows through Paris. Within 5 years after the system was opened submersed aquatic weeds had cut the flow of water in the main canal by 80 percent.

Man's efforts to increase food production in the United States have resulted in treatment of 105,833 kilometers of irrigation and drainage channels for aquatic weed control in 17 western states (*1*). This represents about 55 percent of the infested channels and about 45 percent of the total length in use. Greater world pressure for food production will increase the demand for even more efficient control of vegetation which interferes with water flow.

Man's quest for beauty and recreation has brought about some of the most catastrophic of our weed problems. Exotic and beautiful aquarium species are transported throughout the world. *Egeria, Cabomba, Elodea,* and *Hydrilla* are examples of submersed plants that have been carried from one country to another with dire consequences (Figs. 7 and 8). The problem is twofold. First, in the United States and most other countries there are no limitations on the importation of aquatic plants. Second, most of the aquatic plant dealers grow and harvest the plants in public waters. When a grower desires another species, he simply imports it, places it in several streams or lakes, and then harvests it as it is needed. Many submersed weeds have been introduced in this manner. Failure to restrict their movement has allowed wide distribution of some species.

Emersed Weeds

Emersed aquatic weeds have their roots beneath the water and their stems and leaves above the surface. Many are familiar, including the bulrushes, *Scirpus*; cattails, *Typha*; water lily, *Nymphaea*; spatterdock, *Nuphar*; rushes, *Juncus*; arrowhead, *Sagittaria*; and alligatorweed, *Alternanthera*. Where water levels fluctuate these species may survive for short periods as terrestrial plants. Many are the first to invade newly flooded areas, and they will prosper in the backwater areas which are intermittently wet. Emersed weeds are especially troublesome in irrigation and drainage systems. They choke canals, increase silt deposition, and impede water flow. Frequently, the design rate of flow can never be achieved because of encroachment of plants on the shoreline and the water lost through transpiration.

Phreatophytes

These are the plants that grow at the water's edge or with their roots reaching into the capillary zone overlying the water table. It is as difficult to determine limits for the species which should be in this group as it is to define the shoreline in a swamp. Woody plants, perennial grasses, and broadleaved plants are prominent in this group. There are an estimated 6 million hectares of stream channels, canals, reservoirs, and river flood plains infested with these weeds in the western part of the United States, and they waste 25 million acre-feet of water annually. It would be practical to save 25 percent of this wasted water by maintenance of stream channels and effective weed control (*15*).

The most common woody plants are salt cedar, *Tamarix pentandra*; willows, *Salix* spp.; cottonwood, *Populus* spp.; baccharis, *Baccharis* spp.; buttonbush, *Cephalanthus occidentalis* L.; velvet mesquite, *Prosopis juliflora*; and grease wood, *Sarcobatus vermiculatis*.

Floating Island Weeds

In accord with many natural growth cycles, large masses of floating dead aquatic vegetation may support progressively larger types of vegetation. As these enter the final phase of this ecological succession, woody species become established. Large islands bearing trees several feet in circumference are impossible to cope with when they lodge in the channels of main streams, for example.

One of the most dangerous and dreaded weeds of the African waterways is papyrus, *Cyperus papyrus* L., of the sedge family Cyperaceae. It is feared because it may encroach on open water by extending from the banks. It is one of the principal plants in the formation of sudd which is a mass of free-floating vegetation. The plant grows upright to a height of 4 to 5 meters. The rhizomes by which it spreads vegetatively are woody and strong and may reach far out into open water or may quickly travel over weed mats or penetrate through them and thus knit them together. These massive and sturdy floating islands of vegetation, when loosed on a river at any season, can be a menace to navigation. Sudd formation in two of Africa's largest swamps, the Okavango in Botswana and the great swamp in the White Nile above Malakal, are dominated by papyrus. A study of the papyrus sudd of the White Nile revealed that 50 percent of the water entering the river was lost through evaporation and transpiration as a result of the activity of this weed and its associated vegetation.

Vossia cuspidata (Roxb.) W. Griff., a robust member of the grass family Gramineae is frequently mixed with the islands of associated plants. The weed is sometimes called hippo grass, because it is grazed by the hippopotamus as well as by cattle. It can have floating or submersed stalks which grow rapidly for considerable distances under favorable conditions. The aerial portion of the stem is strong and erect and may reach a height of 2 meters. The grass is widely distributed in Africa and Asia. The irrigation canals of the Gezira cotton scheme along the Blue Nile are sorely troubled with this grass because it impedes the flow of water.

Chemical Control

Many selective herbicides have been developed to combat aquatic weeds. Some have such a narrow range of specificity that one species of a genus may be controlled without affecting other species of the same genus. Thus certain problem species can be controlled without adversely affecting the desirable flora and fauna in a waterway. Formerly, large quantities of toxic chemicals, such as sodium arsenite, were used indiscriminately; but today the herbicides used in our waters must pass rigid tests on efficacy, toxicity to fauna and flora in and near the waterway, residues in irrigated crops, and many other hazards.

Chemical control of several floating weeds is possible. Water hyacinth is "managed" and kept under control in the United States with 2,4-D (2,4-dichlorophenoxyacetic acid). At one time the infestations of this weed on the White Nile and the Congo rivers in Africa were controlled with the same herbicide, but now political turmoil and

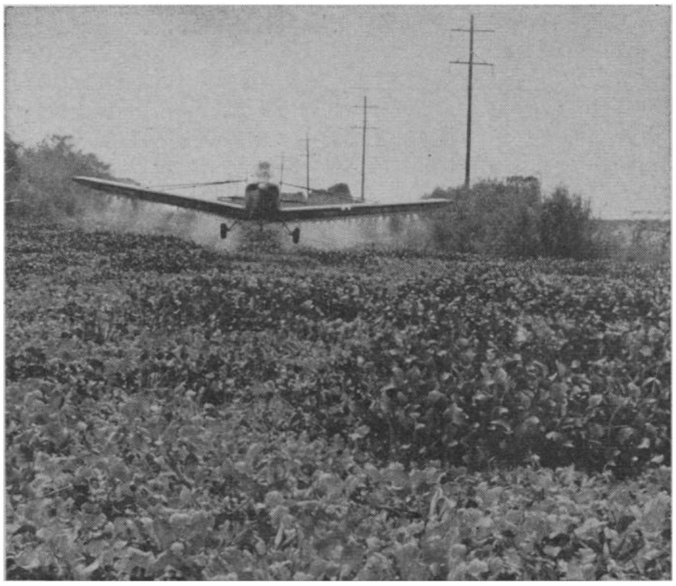
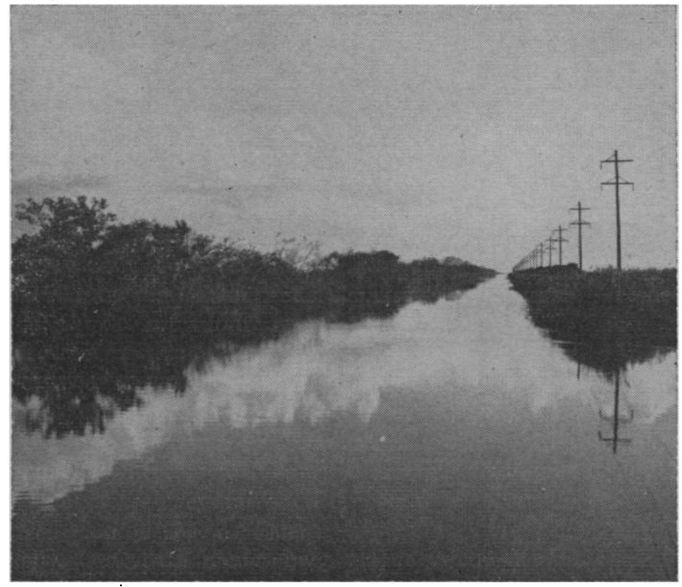

Fig. 9. Diquat was applied at 1.7 kilograms per hectare to control water lettuce (left) and resulted in complete control within 30 days (right).

economic problems have made it impossible to continue the control operations.

If sensitive crops are grown in agricultural areas adjacent to infested waterways, some herbicides may not be used because of the danger from volatility and spray drift. Recent development of invert emulsion (water in oil) formulations of 2,4-D, water thickening agents, and new innovations in spraying equipment (such as the microfoil boom) give the applicator new tools to control placement of the chemical. Diquat (6,7-dihydrodipyrido[1,2-α:2′,1′-*c*]pyrazidiinium dibromide) has proven effective on water hyacinth at 1.7 kilograms per hectare and can be used with greater safety around ornamentals and crop plants that are very sensitive to 2,4-D. Two applications of diquat usually give about the same control of this weed as would be expected from four treatments with 2,4-D. In Australia, amitrole-T (3-amino-1,2,4-triazole + ammonium thiocyanate) has been used effectively on water hyacinth (*16*).

Diquat is also effectively used to control water lettuce at the same rates as it is used to control water hyacinth. As these two plants often grow together, a single application of diquat can be used to control both species (Fig. 9).

The chemical control of submersed weeds, much more difficult, is achieved through the use of chemicals with several different modes of action. Large quantities of emulsified xylene and other aromatic solvents are used for contact control of vegetation in irrigation canals. The xylene is usually released into the flowing canal, over a 30-minute period, at 6 to 10 gallons per cubic foot per second of flow. As the chemical moves down the canal, the plants absorb lethal doses, the treated portion of the water is spilled into a waste area, and the untreated flowing water is then available for immediate use. The treatment kills the vegetation back to the bottom mud, but regrowth may occur in a few weeks.

Acrolein (acrylaldehyde) is applied in flowing water in the same manner as aromatic solvents (*17*). In static water sites such as lakes, acrolein (7 parts per million by volume) is injected directly into the water. *Hydrilla* has been controlled with this method for 8 to 16 weeks in both the United States and Australia. Generally two to four treatments are required per year for satisfactory weed control.

Knowledge of the plant cycle has an important bearing on the control of submersed weeds. Sago pondweed, *Potamogeton pectinatus*, and *Hydrilla* produce hydrosoil propagules. In canals that can be dewatered, fenac (2,3,6-trichlorophenylacetic acid) and dichlobenil (2,6-dichlorobenzonitrile) can be applied to the dry canal bottom. The chemical is then leached into the surface soil and released into the water as growth begins. *Hydrilla* also produces large numbers of hydrosoil turions that sprout as soon as the topgrowth is killed. In areas that cannot be dewatered, successive treatments with fatty acid amine salts of endothall (3,6-endoxohexahydrophthalic acid) and diquat reduce the number of these propagules to the point where regrowth is minimum (*18*).

Foliar treatments with dalapon (2,2-dichloropropionic acid), at 5.6 to 22.4 kilograms per hectare, will afford quite satisfactory control of most aquatic grasses, cattails, and rushes. Often two or more treatments are required in a growing season.

Amitrole-T is another selective herbicide that is effective on grasses. The response of shore weeds to these two herbicides provides us with an example of the interrelation of stage of development and herbicidal activity. Dalapon is most effective on cattails before they flower, while amitrole-T is more effective in the fall, after flowering. A combination or mixture of these two herbicides is often used as a single application that may be effective for several months and which may cover a broader spectrum of weeds. A mixture of dalapon and 2,4-D is sometimes used where control of both grass and broad-leaved species is necessary (*19*).

There are still many troublesome species for which there are no mechanical, chemical, or biological controls. For most of these we lack information on the physiology and the stages of growth and development. The pace has quickened in the search for ideas, chemicals, and methods for the selective control of aquatic vegetation. Modern herbicides may also be used safely to keep our waterways productive and useful. However, application of most herbicides to potable water is restricted. Some are toxic to fish. Information is needed on the disposition and effects of herbicides in water, in crops irrigated with treated water, and in fish. Because the cost is generally only 10 to 20 percent of other control methods, there is frequently no other practical way to manage the vegetation in a stream, a lake, or a power system.

We do not know whether we shall be able to restore our water resources. It is certain that we shall continue to use them, and many of them are destined to be misused for some time to come. Some types of aquatic vegetation will flourish; we shall find it disagreeable, and sometimes we shall be overwhelmed by its luxuriant growth. Until we have become wise enough to appreciate our water, and until we have come to respect it as one of the most precious of all the gifts of nature, aquatic herbicides will be needed—for they will be one of the few tools that we can afford in the selective management of the vegetation in our waterways. In many places in the world there will be no other choice.

Biocontrol

Natural forces affect aquatic plant growths. These forces are used by man in his biological control programs (biocontrol). Biocontrol, which turns nature against herself, may be the most economical method for the control of portions of this perplexing world problem. Biocontrol has certain advantages, for example, relatively low program costs, ready suppy sources, ease of application of techniques which often require no special equipment, minimal training of unskilled personnel, and relative permanence of treatments because of the ability to resist weed reinfestations (*20*). In this age of emphasis on chemical and mechanical control of aquatic weeds, most people are unaware of the progress being made in biocontrol. Emphasis on this area of weed control has increased rapidly during the last decade.

Biocontrol works best with agents of foreign origin. Scientists have traveled to the native homes of certain species of aquatic plants to collect various organisms that attack the plants. Frequently, in its native habitat, the plant never presents the problem that it does in other parts of the world. The reason for this is that certain natural agents, such as insects, diseases, and the chemistry of the water, have controlled the plant. For this reason the biocontrol of aquatic vegetation should not be confused with aquatic plant eradication. The plant and the biocontrol agent are part of the aquatic ecosystem.

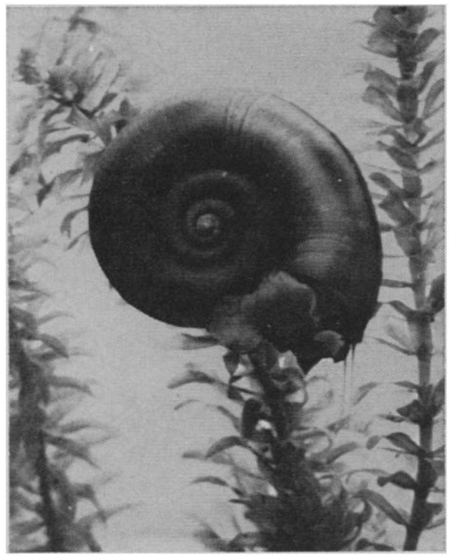

Fig. 10. A freshwater snail, *Marisa*, feeding on *Hydrilla*.

In nature, a balance is maintained in the aquatic flora through plant-feeding insects, diseases, nematodes, fungi, bacteria, viruses, fish, snails, and mammals. When a biocontrol agent is selected it must be thoroughly investigated before introduction into a new area. It must not be released if it will attack desirable plants or other organisms.

A large freshwater snail *Marisa cornuarietis* has freed small ponds in the southern United States and Puerto Rico of submersed weeds (Fig. 10). *Marisa* carries no diseases of man and has been used as food in Puerto Rico. The indiscriminate feeding habits of *Marisa* have also made it a biocontrol agent for disease-carrying snails. A major disadvantage is its sensitivity to temperatures below 6°C. It may feed upon certain desirable plants such as rice, watercress, and water chestnuts which are growing in the water. A second freshwater snail, *Pomacea australis*, shows promise as a biocontrol for submersed and floating aquatic weeds. This large ampullarid is widely distributed in Brazil (*21*).

Mammals with aquatic weed-cleaning ability are rare, but the sea cow or manatee, *Trichechus manatus latirostris*, has shown its taste for many types of aquatic weeds. Unofficial reports collected from all areas of the world indicate that this mythological mermaid has no peer in the biological world for the volume of aquatic weeds which can be consumed by one animal. There is only limited use of the manatee because of the scarcity of animals, and an increase in population is uncertain because of the lack of knowledge about its reproduction (*22*).

In contrast to the indiscriminate feeding of snails and manatees is the fastidious taste of the alligatorweed beetle, *Agasicles* sp. In nature this small beetle feeds only on alligatorweed and will starve in its absence. No control technique could be simpler than the release of a handful of beetles into an infestation of alligatorweed. Recent laboratory research has also shown that *Salvinia* may be controlled by a wingless aquatic grasshopper *Paulinia acriminate*. *Paulinia* is now being evaluated in field trials at Lake Kariba. Investigations are also underway to search for natural enemies of the water hyacinth in its native South American home (*23*).

Certain freshwater fish consume large quantities of aquatic vegetation. The common carp, *Cyprinus carpio*; Chinese grass carp or white amur, *Ctenopharyngodon idella*; tilapia, *Tilapia* sp.; and silver dollar fish, *Metynnia* sp., are used for control of aquatic vegetation in many areas of the world. Many of these species are sensitive to cold weather and, in colder climates, must be overwintered in temperature-control tanks. The most promising of this group is the white amur. Ponds choked with *Hydrilla* in India were cleared of the weed in 2 months after they were stocked with 350 white amur per hectare (*24*). Russia, Poland, Czechoslovakia, China, and other countries have used the white amur as a biocontrol for aquatic weeds.

Ducks, geese, and swans can remove small amounts of vegetation, and they are especially effective in small ponds for the control of duckweed. Controlled grazing of cows, horses, and goats may be used to hold down vegetation along lake shorelines and canal banks (*25*).

Diseases, viruses, fungi, bacteria, and nematodes have received very little attention in aquatic weed biocontrol research. Two diseases are considered to be the cause of the decrease in eurasian watermilfoil in the United States (*26*). The diseases have not been identified and may be only an indirect cause of the decline in the milfoil. A disease was the direct cause of the decline of eel grass along the Atlantic Coast of the United States in the 1930's.

Low-growing species of aquatic plants, several centimeters in height, have been planted in canals to compete with the more undesirable species that may attain lengths of several meters.

Removal of nutrients from the water environment by partitioning agents is also being considered as a biocontrol agent. Some success has been obtained in controlling submersed aquatic weeds with selective dyes or black plastic that filter out all, or selective portions of, the sunlight in water.

The employment of biocontrol agents in our aquatic weed programs offers a new approach to the solution of an old and aggravating problem. Combinations of biocontrol agents with chemical and mechanical methods of control may someday be the answer to aquatic vegetation management.

Mechanical Removal

The first effort to control aquatic weeds was with hand tools. Since 1900, many machines have been designed to perform such work, and some are so large that several barges are required for flotation. In the United States today there are still many canals and drainage systems maintained by power shovels and draglines, but these machines work slowly and maintenance costs are high. Emersed weeds are sometimes controlled with the use of underwater mowing machines (*27*). All of these types of mechanical equipment can bring temporary relief from weed infestations and sometimes provide channels through portions of an otherwise inaccessible waterway. When water is used for human or animal consumption, or when valuable crops are in the immediate area, there may be no practical way to control aquatic weeds except by mechanical removal. The ratio of costs for these methods as compared to approved herbicidal methods may be on the order of ten to one (*8*).

Because large quantities of nutrients accumulate in the tissues of some aquatic weeds, the removal of a heavy stand may be beneficial to the waterway. The yield of such massive quantities of green vegetation raises the question of its value for food, for food amendments, or for improvement of soils. But such questions have already been raised, again and again, as to unwanted terrestrial plants (such as woody species that might be used for lumber and wood products) or as to perennial grasses that might be used for pasture. There are many reports of analytical work on water hyacinth and several other aquatic weeds (*28*). There is no shortage of information on percent dry matter, crude fiber and protein content, or carotene and other special constituents of these plants. Why, then, have aquatic weeds not been more widely used? The answer is that we lack economical ways of harvesting and processing large masses of plants with a very high water content. In certain countries the weed nurseries and other important sources of infestation are almost inaccessible. Add to this the probable cost of transport of a finished product over long distances and it becomes easy to see why public and private agencies have not accepted these risks.

Summary

The great focal points of civilization placed their roots along streams and in sheltered harbors because man needed to be near water for navigation and housekeeping and because it provided protection. There was little thought of caring for the bountiful supplies of water which seemed endlessly renewable. Within living memory the supplies of fresh water in the beautiful streams and lakes of North America were legendary. But suddenly in the 20th century we have at last begun to sense that both the water and soil of the earth are limited. We now realize that we cannot run off to a clean new place each time we have fouled our nest. We shall have to learn to manage our affairs and our immediate environment. We are sickened by the spectacle of the trash and refuse of our own activity. We become uncomfortable in our role as stewards of this wonderful resource, for we do not understand how we may both use and protect it.

While we have been engaged elsewhere, the rampant growth of aquatic weeds has come to be one of the symptoms of our failure to manage our resources. We assign values to the depreciation of property, to the pollution of municipal water supplies, to the loss of navigable streams, and to the failure of irrigation and power systems because of aquatic weeds. But we must also judge the worth of clean water for man in other, quite different ways. Some of the loveliest places on earth are at the water's edge. These may be the sites of our dwellings or the places that we choose for rest and renewal. As we spoil these, one by one, we shall know that we have surrendered a great part of our humanness, and we shall be anxious because we cannot trust ourselves.

Now we must abandon our view that streams and lakes are great self-cleansing reservoirs that can receive our wastes forever and return to us always as cool, clear water. Many of the watercourses of Asia and Africa, and of Wisconsin and Florida, are now so fertile and so well innoculated with aquatic weeds that they can no longer correct themselves. In many of these places, it is now too late to talk about an equilibrium or the balance of nature. Human activity and neglect have driven the equation far to the right. Within the combinations of mechanical, biological, and chemical methods of aquatic weed control we can find the tools to help with their restoration. We can keep the waterways open so that they can be useful to man and so that he may enjoy them. We can buy the time we need to learn to manage not only the vegetation but each of the resources in an entire watershed.

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The Earliest Americans

New developments increase the known antiquity of man in the New World but leave many problems unsolved.

C. Vance Haynes, Jr.

During the 19th century several discoveries were made in America suggesting the presence of man during the Ice Age, but the evidence was inconclusive. Two schools of thought developed. One held that evidence of the presence of man in the New World did not extend back much beyond the obvious evidence of the prehistoric Mound Builders, Pueblos, Aztecs, or Incas of no more than 2000 B.C. The other school held that man lived among, and hunted, the giant game animals that became extinct at the end of the Pleistocene (*1*).

It became apparent that, if the truth were to be known, the skeletons of late Pleistocene game animals would have to be scientifically excavated by trained observers, to see if any evidence of man could be found. If it could be, the undisturbed association of artifacts with bones of an extinct animal in geological deposits of Pleistocene age could be presented to witnesses from the scientific community for verification. Such was the case in 1926 when paleontologists from the Denver Museum of Natural History discovered fluted stone projectile points in association with skeletons of extinct bison near Folsom, New Mexico (*2*). The following year, as more bones and "Folsom points" were found *in situ*, scientists from various parts of the continent witnessed the discovery, and in subsequent years more than 100 sites have been described where artifacts of early man occur *in situ* with bones of either mammoth, camel, extinct horse, or bison (*3*).

In the United States today we have an excellent, but by no means complete, understanding of cultural development during the final phase of the Pleistocene glaciation, known as the Valderan Substage. As for the earlier substages, after 40 years of searching, little positive evidence for earlier occupation of the New World has been found. But, as discussed below, we may be on the threshold of a second breakthrough regarding knowledge of the antiquity of man in America.

Geochronology

At the time of the Folsom discovery it was not possible to estimate the age of the find any more precisely than to say that the association with *Bison antiquus* meant that man was present in America near the end of the Ice Age. Today our understanding of the time range for early man is much more precise because of the study of geological sequences to which archeological finds can be related. Radiocarbon dating has made possible both the precise dating and the accurate correlation of these sequences in widely separated areas (*4*).

The study of stratigraphic sequences of loess, till, and lake sediments in the mid-continental area has provided a record of geological time corresponding to the fluctuations of late Pleistocene glaciers, but occurrence of archeological sites within these strata are rare. Most of the stratigraphic record of early man is in the western United States, where erosion and sparse vegetation provide better exposures for the accident of discovery. For convenience of discussion I have subdivided the Paleo-Indian period, or the time of early man, into three hypothetical subperiods (Fig. 1) and have arbitrarily selected the boundaries to correspond to those of the time-stratigraphic subdivisions of the Wisconsinan stage as defined by Frye and others (*5*).

The late Paleo-Indian period corresponds to the Valderan substage of between 11,800 and 7000 years ago.

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