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Pollen Influx and Volcanic Ash

The pollen content of Mazama and Glacier Peak ashes reveals details of their depositional chronologies.

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Summary. Pollen influx can be used to estimate the duration of short-term depositional events. When applied to volcanic ashes, it may also provide information on the season and ecological effects of ashfall. In our initial application of the method to volcanic ashes from Lost Trail Pass, Bitterroot Mountains, Montana, we have illustrated that (i) two falls of Glacier Peak ash, which occurred about 11,250 ^{14}C years ago, were separated by 10 to 25 years; and (ii) volcanic ash from a major eruption of Mount Mazama (about 6700 ^{14}C years ago) first fell in the autumn and 4.6 centimeters of ash was deposited before the following spring. We also believe there is a reasonable probability that (i) about 1 centimeter of ash fell during the following year and about 1.7 centimeters fell the year after; (ii) in all, the sporadic primary Mazama ashfall lasted for nearly 3 years; (iii) Mazama ash resulted in low lake productivity, as measured by the occurrence of *Botryococcus* and *Pediastrum*; (iv) Mazama ash, perhaps through a mulching effect, may have produced increased vigor and pollen production in some sagebrush steppe genera; and (v) as measured by the records of fossil pollen and acid-resistant algae, effects on the aquatic and terrestrial ecosystems were short-lived. With refinement of the methods and broader geographic application, pollen influx studies may prove valuable for separating the regional and chronological details of tephra attributed to Mazama, Glacier Peak, and other Cascade Range volcanoes.

Glacier Peak, Washington, and Mount Mazama (Crater Lake), Oregon, are two of the many Cascade Range volcanic vents that produced widespread ash deposits in northwestern North America. These volcanoes have been objects of study for many decades, and the ashes are routinely used as chronological markers over distances of more than 1000 (Glacier Peak ash) and 2000 kilometers (Mazama ash) (*1*). Our initial examination of the fossil pollen content of these ashes at several localities revealed considerable variation in both pollen numbers and types, and we believed that such variability might provide clues to the duration, season, and ecological effects of the ashfalls. Therefore, ashes contained in lake sediments of Lost Trail Pass Bog, Bitterroot Mountains, Montana (Fig. 1), were studied in more detail. Specifically, we hoped to test the potential of pollen influx as a tool with which to estimate the durations of ashfalls and the intervals between them.

We chose Lost Trail Pass Bog for this study because the Glacier Peak and Mazama ash layers (Fig. 2) in our 10-centimeter-diameter lake sediment cores represented primary deposition, as indicated by the lack of detrital materials from surrounding soils. Also, their boundaries were distinct, they had clear laminations indicating deposition into standing water, and they were well dated (*2*). Identification of both ashes was confirmed by refractive index, phenocryst suite, and microprobe analysis of major elements (*3*).

At Lost Trail Pass, Glacier Peak ash (5.73 to 5.77 meters in depth) is represented by two distinct ashes separated by 7.5 millimeters of lake sediment. Both ashes are laminated, but a turbation zone occurs within the upper ash (Fig. 2). Lake sediments below and above the two ashes gave radiocarbon ages of 11,200 ± 100 (sample WSU-1548) and 11,300 ± 230 (WSU-1554) years. These are younger than the ages of 12,000 to 13,000 ^{14}C years most often cited for Glacier Peak ash (*1*). It is now clear, however, that several eruptions of Glacier Peak produced volcanic ashes of different geographic ranges and ages (*4*) and that the Lost Trail Pass Glacier Peak ashes are referable to the uppermost of three main Glacier Peak ash deposits (*5*). The occurrence of lake sediments between ashes provided the opportunity to measure the interval between ash falls by pollen influx.

The Mazama ash (5.05 to 5.13 m in depth) consists of at least 23 graded laminations from 0.5 to 10 mm thick. Lake sediments on either side of the ash were radiocarbon-dated at 6700 ± 100 (WSU-1552) and 6720 ± 120 (WSU-1553) years ago. The 6700-year date compares favorably with other dates for Mazama ash. The thickness of the ash allowed us to investigate ashfall duration through total pollen content and the pollen sequence within the ash.

Pollen Influx

Pollen influx is an estimate of the number of pollen grains incorporated into sediments with a particular surface area within a particular time. It may vary with vegetation type and density and is therefore an important tool for reconstructing vegetational history from fossil pollen assemblages. Pollen influx per square centimeter per year can be estimated if the deposition rate and the number of pollen grains per volume of lake sediment are known. For example, if 1 cm^3 of lake sediment containing 100,000 pol-

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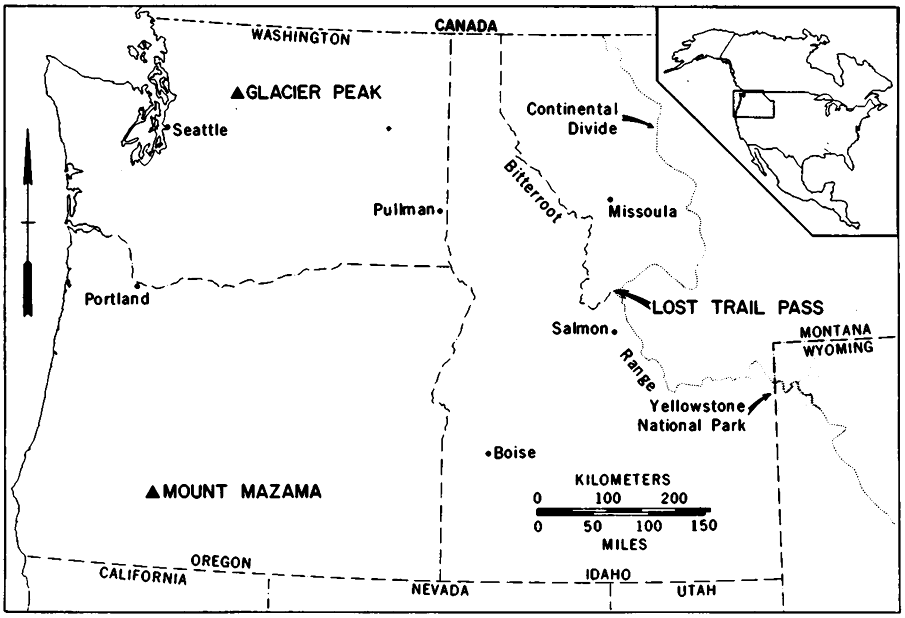


Fig. 1. Map of the northwestern United States, showing the locations of Glacier Peak, Mount Mazama (Crater Lake), and Lost Trail Pass.

len grains was deposited in 25 years, then on the average 4000 pollen grains were deposited on a 1-cm² surface during each of the 25 years represented by the volume (*6*). Conversely, if the pollen influx is known, the number of years contained in a particular volume of sediment can be estimated (Fig. 3).

For Lost Trail Pass Bog, the deposition rates were determined from 16 radiocarbon dates and total pollen was estimated by adding 100,000 tracers (*Lycopodium* spores) (*7*) to each of 81 2-cm³ samples as the first step in microfossil extraction (*8*). The ratio of *Lycopodium* spores to pollen grains permitted calculation of population estimates for each sample. The 6.27 m of sediment, spanning the past 12,000 years, was divided into seven pollen zones characterized by distinctive proportions of tree, shrub, and herb pollen and algae. Finally, the pollen influx for each zone was estimated from the average pollen content of all samples of the zone (*2*).

The two layers of Glacier Peak ash occur within pollen zone 2 and are separated by 7.5 mm of lake sediment. This zone was deposited between 11,550 and 6950 ^{14}C years ago and is characterized by haploxylon pine pollen (probably whitebark pine). A mean influx of 4648 pollen grains per square centimeter per year was estimated from 15 samples. Mazama ash occurs within zone 3 (6950 to 4800 ^{14}C years ago). This zone is characterized by dominance of diploxylonoid pine (probably lodgepole pine) and Douglas fir or larch pollen. The average pollen influx for the nine samples from zone 3 is 4056 grains per square centimeter per year (*2*).

We assume that 4648 and 4056 grains per square centimeter per year for zones 2 and 3 are reasonable estimates of pollen influx to lake sediments before and after the ashfalls. Thus, an estimate of 4000 pollen grains from a 1-cm² column of Mazama ash would indicate a depositional duration of about 1 year. The example from the Lost Trail Pass Bog Mazama ash is illustrated in Fig. 3; a 1-cm² column of the Mazama ash containing 11,485 pollen grains would have been deposited in about 2.8 years.

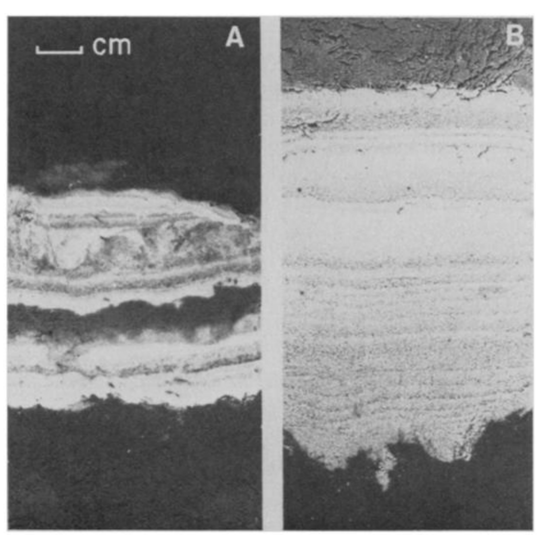


Fig. 2. (A) Glacier Peak and (B) Mazama ash layers in lake sediments of Lost Trail Pass Bog, Montana.

The Glacier Peak Interval

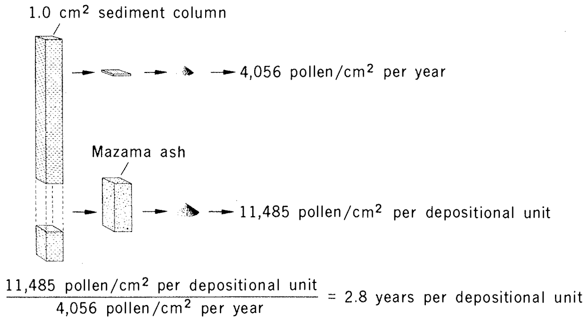
The estimate of pollen deposited per unit volume for lake sediments between the Glacier Peak ashes was derived by packing a 2-cm³ round-bottom scoop (*9*) with the interash sediments and adding 100,000 *Lycopodium* spores. As illustrated in Fig. 4, if this method is used, the sample height of 7.5 mm must be considered in obtaining the estimate of 15.7 years. This estimate could be affected if the ashfall influenced vegetation and pollen production. This seems not to be the case, however, because the proportions of the pollen types from above, below, and between the ashes were nearly identical. When possible errors of sampling and population estimation are considered, 10 to 25 years seems reasonable for the Glacier Peak interval (*10*).

The Mazama Ashfall

Packing calibrated spoons is a standard palynological practice and was adequate for sampling the Glacier Peak interval because there was very little mixed ash in the organic lake sediments. However, our experience indicates that it is not the desired method for sampling ashes. The excavation and packing of volcanic ash tends to break and rearrange the shards to produce a sample with a higher bulk density than the source. This increases the population estimates per volume of sediment and distorts the interpretation of the pollen influx. Therefore, a sampling plan was developed specifically for the Mazama ash.

To avoid the packing problem, the ash was left undisturbed by excavating with a razor blade around a 1-cm² column, 7.3 cm in height. This provided a sample with a constant cross-sectional area and ensured uniform representation of all portions of the column. The column was further divided into eight subsamples at 1-cm intervals (the top and bottom samples were 0.7 and 0.6 cm tall). We avoided contamination from adjacent lake sediments by sacrificing a thin (< 0.5 mm) layer of ash. This was particularly important because the adjacent lake sediments contained 50 to 350 times more pollen per cubic centimeter than the ash.

There are no significant differences in pollen content between the lake sediments directly above or below the volcanic ashes (*2*). In fact, were the ashes not present, we would have been unaware that a possibly catastrophic event had occurred. Assuming that effects on



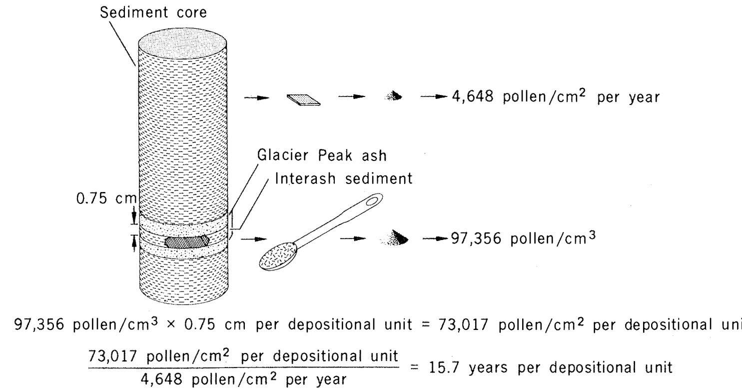


Fig. 3 (left). Diagram illustrating the calculation of ashfall duration from pollen influx to a 1-cm² column of Mazama ash. The average pollen influx for pollen zone 3 is shown. Fig. 4 (right). Diagram illustrating the calculation of the interval between Glacier Peak ashes from pollen influx to lake sediments separating the ashes. The calculation must include the sample height as well as the pollen concentration. The average pollen influx to pollen zone 2 is shown.

vegetation are reflected in the pollen content within the ash, we analyzed the eight samples from the 1-cm² column in the hope of establishing the season and any apparent ecological effects of the Mazama ashfall. We also wished to learn whether the ashfall duration of about 2.8 years could be confirmed from the distribution of pollen types as well as from total pollen influx. For example, sagebrush (*Artemisia*) blooms in the fall and a disproportionate percentage of its pollen (as compared with the average for zone 3) would provide evidence for autumn deposition; the following spring and summer would be indicated by pine pollen dominance.

Microfossils were extracted (*8*) after adding 25,000 *Lycopodium* spore tracers to each subsample, and pollen, algae, and tracer spores were counted until either 500 pollen or 4500 *Lycopodium* were recorded. The five pollen groups plotted in Fig. 5 were selected because they were the most abundant types in the Mazama ash, and they illustrate the succession of pollen deposition through the ash. Only pine and perhaps some grass and some taxa of the "other pollen" category represent local pollen production. Today, dense coniferous forest extends several dozen kilometers in most directions from Lost Trail Pass (*2*). Only downwind to the east (beginning about 12 km away in Big Hole Valley, Montana) and far to the south (beginning about 50 km away near Salmon, Idaho) are there considerable expanses of sagebrush (*Artemisia tridentata*) steppe.

The saltbush-greasewood pollen category in Fig. 5 includes pollen of the Chenopodiaceae, with *Sarcobatus* (greasewood) accounting for 23 percent of the total. Greasewood is the most easily recognized, commonly occurring pollen type resulting solely from long-distance transport. It now grows no closer than about 50 km to the south in the Salmon Valley, Idaho, and 90 km to the east in the Beaverhead Valley, Montana, but it only becomes abundant 250 km away on the Snake River Plain. Greasewood occurred in 66 of the 81 samples analyzed from Lost Trail Pass Bog and accounted for 26 percent of total Chenopodiaceae pollen. In the northern Rocky Mountains, Chenopodiaceae pollen may be abundant in sagebrush steppe, but it is relatively unimportant at higher elevations (*11*).

Although detailed studies of annual pollen production are not available for the northern Rocky Mountains, our field observations and published atmospheric pollen studies (*12*) permit some generalizations. On the average, pine and grass pollen are first apparent in May, reach their maximum in June, and decrease rapidly through late July and August. Saltbush-greasewood pollen increases gradually from May through August and decreases through September and early October. Most local species of sagebrush bloom from late August through October. Depending on climatic conditions, the dates of flowering of individual species at various elevations may vary from 3 to 6 weeks; however, the order of flowering is usually the same.

The sequence of pollen deposition within the ash (Table 1 and Fig. 5) shows three major events (*13*). The 4.6 cm of the lowest five samples is characterized by few pollen grains and dominance of nonarboreal types that could result from rapid deposition or low availability of pollen. By contrast, the next centimeter of ash (2.7 to 1.7 cm in depth) contains a full year or more of pollen dominated by pine. Compared with the zone 3 average, the upper two samples (1.7 to 0.0 cm in depth) contain pollen produced by pine and sagebrush in about 1 year and a higher than expected content of grass and saltbush-greasewood pollen for the same period. This 7.3-cm sequence could represent an initial major ashfall during the autumn and winter, less deposition during the following year, and a twofold increase in deposition during the next year. Our explanation of the depositional sequence of pollen and algae and the nature of the sediments support this interpretation.

The extremely low pollen influx into the lowest five samples (4.6 cm) of Mazama ash and the dominance of pollen

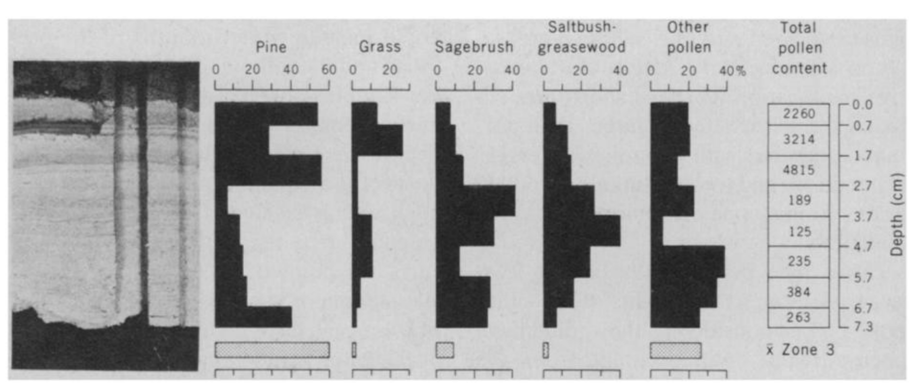


Fig. 5. Pollen percentages and total pollen content of eight samples of Mazama ash compared to average percentages for pollen zone 3. The samples were collected from the isolated 1-cm² column of ash shown in the photograph.

Table 1. Estimates of pollen population and influx duration for eight samples from a 1-cm^2 column of Mazama ash (Fig. 5). Influx durations were calculated for both selected taxa and total pollen content by comparison with the average pollen content per square centimeter per year in lake sediments from the pollen zone (zone 3) containing Mazama ash (2, 13). Pollen content values are number per square centimeter per year.

Sample depth (cm)	Pine		Grass		Sagebrush		Saltbush-greasewood		All others		Total	
	Pollen	Years	Pollen	Years	Pollen	Years	Pollen	Years	Pollen	Years	Pollen	Years
0.0–0.7	1,180	0.49	285	2.91	148	0.36	148	1.18	499	0.49	2,260	0.56
0.7–1.7	921	0.38	850	8.67	338	0.81	410	3.28	695	0.68	3,214	0.79
1.7–2.7	2,664	1.11	143	1.46	664	1.60	689	5.51	655	0.64	4,815	1.19
2.7–3.7	11	0.01	6	0.06	78	0.19	50	0.40	44	0.04	189	0.05
3.7–4.7	17	0.01	13	0.13	38	0.09	50	0.40	7	0.01	125	0.03
4.7–5.7	33	0.01	25	0.26	29	0.07	58	0.46	90	0.09	235	0.06
5.7–6.7	65	0.03	15	0.15	110	0.26	61	0.49	133	0.13	384	0.09
6.7–7.3	101	0.04	4	0.04	72	0.17	18	0.14	68	0.07	263	0.06
Total	4,992	2.08	1,341	13.68	1,477	3.55	1,484	11.86	2,191	2.15	11,485	2.83
Mean, zone 3	2,394	1.00	98	1.00	416	1.00	125	1.00	1,023	1.00	4,056	1.00

that was transported over a long distance indicate that most of the ash was deposited during a time when pine was not flowering. The high relative abundance of sagebrush and saltbush pollen would be expected to occur during the fall and perhaps winter months. At these times pollen on the dry soil surface at lower elevations is recirculated and transported upward (*14*), whereas at higher elevations pollen is held in the moist forest duff or beneath snow. If the initial ashfall occurred after sagebrush flowered, we would expect a smaller influx and percentage of sagebrush pollen. However, its high relative frequency and influx value (0.78 year in the lowest five samples) suggest that sagebrush was flowering, or its pollen remained on the soil surface where it would have been readily available for resuspension and transport by wind.

Although we believe pine and sagebrush pollen are the best seasonal indicators, the influx values of grass (0.64 year) and saltbush-greasewood (1.89 years) in the lowest five samples must also be considered. The grass values could be indicative of late summer deposition; however, the low pine value (0.10 year) makes this interpretation improbable. Today the pines and most grasses are through flowering before sagebrush begins to flower and the saltbush-greasewood values clearly require an alternative explanation. Perhaps short-term climatic trends resulted in larger than normal (compared with the zone 3 average) production and recirculation of pollen grains from steppe communities at lower elevation.

Since pine pollen grains are at least twice as large as the grains of the other pollen types considered, they could have been "swept" differentially from the lake water if ash first fell in late summer. However, our data do not support this possibility (Table 1). On the contrary, Mazama ash fell when little suspended pollen remained in the water, or suspended pollen was removed gradually as the ash fell, or a relatively constant influx of pollen transported over a long distance accompanied ash deposition.

The fossil algae record also helps to exclude the probability of an initial ashfall in late summer. Certain acid-resistant algae survive chemical pollen extraction; and two of these, *Botryococcus* and *Pediastrum*, were abundant (4300 per square centimeter per year) in lake sediments below Mazama ash. These algae normally increase through the warm summer months and die off as water temperatures decline in fall and winter. A late summer ashfall should have included considerable algae; however, within the lowest four samples, the population estimates for algae decline from only 144 to 0. Thus, the first centimeter of ash must have fallen after the annual die-off had begun and most of the algae had already settled to the lake bottom.

The abrupt increase in the pollen content of the sample from 2.7 to 1.7 cm indicates a slowing of ash deposition (Fig. 5). This sample contains slightly more pollen than expected for the influx of 1 year, but the saltbush-greasewood pollen represents what would be expected in 5.5 years (Table 1). Although the sample could include winter months of the previous and the following year, the two upper samples contain about as much pine and sagebrush pollen as would be expected in 1 year, but more than 11.6 years of grass pollen and 4.5 years of saltbush and greasewood pollen. This discrepancy requires further explanation.

As we pointed out, a comparison of lake sediment samples on either side of Mazama ash gave no hint that vegetation or pollen production had been influenced by the ashfall. However, the discrepancy in the number of influx years estimated from the various pollen types may provide a clue to a short-lived ecological effect. Either the differences are within the normal annual variation (*15*), or pine pollen production was severely reduced, or short-term climatic trends of the time favored steppe vegetation, or pollen production of steppe genera was enhanced by the ashfall. Although all of these factors may be involved, we believe that the last is indicated. Volcanic ash may have a mulching effect (*16*) and semiarid steppe vegetation might have been especially favored by retained soil moisture. If the number of years contained within Mazama ash is best represented by the pine and sagebrush pollen, then the ash fell within two pine and three sagebrush years, and pollen production by steppe vegetation was greatly enhanced during the first two growing seasons after the ash fell. As compared with the average of zone 3, saltbush-greasewood pollen was unusually high during the first flowering season, while grass profited most during the second year.

The sample below Mazama ash contained about 4300 *Botryococcus* and *Pediastrum* specimens per square centimeter per year, whereas the sample above Mazama ash contained about 6000 per square centimeter per year. The 7.3-cm^2 column of Mazama ash contained only 358 *Botryococcus* and *Pediastrum* specimens. These algae are rare in ash from the initial fall because it followed the early autumn die-off, but the low values for algae in the next growing season (or seasons) must have resulted from the detrimental effects of the ash. The addition of volcanic ash obviously had an effect on two genera of algae and, we assume, on other aspects of the aquatic ecosystem as well.

Although it seems reasonable that the rapid fall of volcanic ash could result in a catastrophic decline in algae (*17*), it seems less likely that the sporadic fall of 2 or 3 cm over 10 years or so would maintain this effect. Thus, we view the low counts of algae throughout the ash as supportive of the pine and sagebrush pollen estimate for the short ashfall duration. Also, if more than half of the ash (4.6 cm) fell within a few fall and winter months, it seems unlikely that the remaining 2.7 cm could represent sporadic deposition for more than 2 or 3 years and still lack organic and extraneous mineral matter and obvious evidence of mixing.

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Nutritional Outputs and Energy Inputs in Seafoods

Mary Rawitscher and Jean Mayer

Summary. Energy used by U.S. ships in harvesting seafoods can vary by a factor of more than 100 when the seafoods are compared on the basis of their content of edible protein or line weight. This energy difference bears no relationship to the nutritive value of the food. When protein yield is compared, the energy to harvest some seafoods is in the same range as that needed to grow field crops. There is a large increase in energy consumption after processing, partly because of the small percent of the live weight used for human food.

Until very recently, energy-intensive fossil fuel has been much less expensive, monetarily, than human labor. Little thought has been, or needed to be, given to the extent to which energy use in food production correlates with good nutrition. It is, however, becoming apparent that energy conservation will be increasingly important in every aspect of our economy, including the food system. In an energy emergency, it may well be necessary to have government regulation of energy use. In such a case, in the food industry, consideration should be given to cutting back production of foods that are nonessential and that provide comparatively few nutrients for their caloric contribution before decreasing production of foods with a high nutrient density.

While this principle must, in the end, be applied to all the essential nutrients, it will suffice here to illustrate the proposition with one: protein. How do high-protein foods compare with each other, in terms of energy required at each stage of production and consumption and in terms of their contribution to a diet adequate in the essential amino acids? It is known that much less energy is used to provide protein from field crops such as wheat and corn (*1*), but a small amount of animal-protein food is desirable even in the diet of adults, partly for its contribution of balanced amino acids, partly for its content of vitamin B_{12}, found only in animal foods. Finfish are particularly valuable nutritionally for, in addition to containing vitamin B_{12} and the correct ratio of amino acids, they are low in cholesterol, saturated fat, and calories and high in polyunsaturated fats and the essential fatty acids. This is important since dietary cholesterol and saturated fat are correlated with the incidence of cardiovascular disease, while the polyunsaturated oils have been found to reduce the level of serum cholesterol.

Energy Use in Fishing

In the period 1950 to 1960, the world's fish catch rose almost 150 percent, raising hopes that the seas would provide a solution to the world's food problems.

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