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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However, an increasing amount of energy spent in fishing has not in recent years given proportionately greater yields. Indeed, overfishing has brought about a decrease in the catch of the most popular table fish. Development of long-distance fishing fleets by countries such as Japan and Russia, with sophisticated equipment used to quickly locate schools of fish and sweep an area clean, has helped to bring about (i) international recognition of the need for cooperation in treating fish as a natural resource and (ii) interest in the development of aquaculture and mariculture.

The fossil energy used in fishing cannot be estimated merely by comparing boat types and the kind and amount of fish caught since the energy used depends also on the time spent in fishing relative to the amount of fish caught. Theoretical curves showing the value of the catch in weight relative to the cost, or time, spent in fishing are made to determine the extent an area should be fished. This type of curve shows that the energy cost of fishing for the last few percent of the fish in a school is much greater than that spent to get a majority of the school. According to the Food and Agriculture Organization of the United Nations, the cost per ton of taking the last 2 percent would be about ten times that for the first 98 percent (*2*). Even so, it is usually financially advantageous for a vessel to take the maximum catch since the cost of the fuel is relatively low. Although it does not appear that more of the traditionally fished species could be caught with a greater use of energy (*2*), more food would be provided for man if a smaller percentage of the fish were used as animal feed. In the United States slightly more than half the catch has been used as fish meal (mainly poultry feed) in recent years. In addition, only one-third to one-half of a fish caught for human consumption is actually used for that purpose. The rest, which usually goes into poultry feed, could instead be used for fish protein concentrate. This is a high-protein (75 to 95 percent) powder intended as a supplement to such foods as bread, cereals, and milk (*3*). It has not yet become popular, and as produced commercially in Sweden, it takes considerable energy in processing (*4*). To yield 1 kilogram of fish protein concentrate, 7 to 8 kilograms of fish, usually herring, are used and between 11,300 and 13,000 kilocalories of fuel.

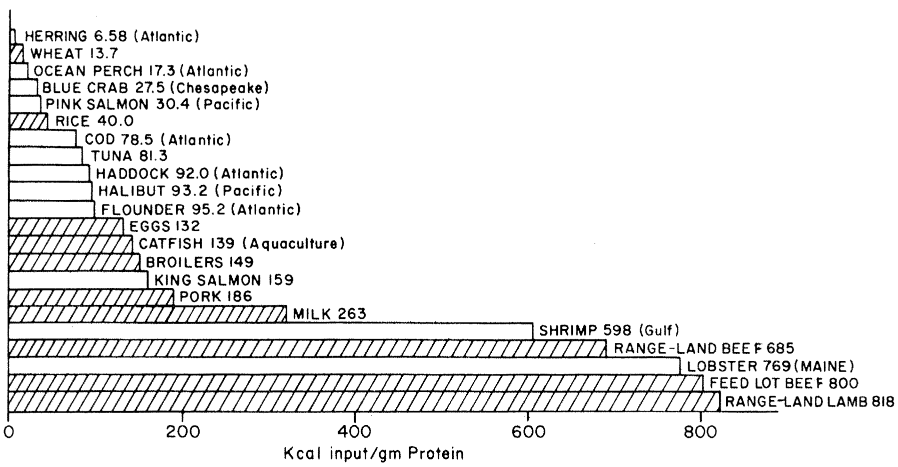

Fig. 1. Energy used to produce a gram of protein in unprocessed foods. The seafood values are from Table 1, column 1, and from the U.S. Department of Agriculture Handbook No. 8 (revised 1963, reprinted 1975) (grams of protein for whole raw seafood). Shaded bars from Pimental (*1*).

Table 1. Energy use in seafood production. Results are given in kilocalories per kilogram. In the columns on harvesting, processing, and seafood processed, fuel and electricity use were calculated from the price paid per kilogram of seafood (*11*) and the average cost of the fuel in the location of the fishery (*12*). Other inputs were calculated from the price paid (*11*) and the appropriate energy coefficient (*6*) and price index (*13*).

Food	Harvesting*	Processing†	Processed seafood‡	Wholesale§	Retail‖	Total¶
Perch (frozen filet)	1,330	4,640	8,470	352	70	8,890
Sardines (canned)	580	12,200	13,800			13,800
Salmon (canned pink)	4,560	11,500	19,000			19,000
Cod (fresh filet)	4,280	5,260	18,500	6.1	110	18,600
Flounder (fresh filet)	5,250	5,130	20,300	6.1	130	20,400
Halibut (frozen steaks)	11,500	5,280	25,800	352	170	26,300
Haddock (fresh filet)	8,070	5,830	28,200	6.1	110	28,300
Salmon (fresh king)	19,800	6,030	33,500	6.1	70	33,500
Lobster (live)	33,700				160	33,900
Tuna (canned)	16,100	8,360	41,500			41,500
Scallops (frozen)			49,800	352	150	50,300
Shrimp (fresh)	74,800	10,000	134,000	6.1	110	133,800
Blue crab (fresh steamed)	2,290	21,500	138,000	6.1	210	137,800

*Inputs include fuel used by the boat, energy to build the boat depreciated over its lifetime, repairs to the boat and equipment, ice, bait, and nets, when used. The round weight of the seafood is used. Scallops were frozen on board, and it was not possible to separate processing from harvesting. The fuel values for tuna purse seine boats were calculated from consumption values given by the Inter-American Tropical Tuna Commission (*14*). Since these ships take on fuel to some extent in Latin America, the amount of fuel can not be calculated from the price paid. †Processing includes the energy in fuels, paper, metal containers, salt, and oil, depreciated energy use in producing the machinery, expressed as kilocalories per kilogram of product. ‡These values include, in addition to the values in column marked †, the energy of harvesting a round weight of seafood sufficient to give a kilogram of product. §For frozen foods, this estimate is based on storage for 90 days in a unit three-fourths full holding 1090 kg/m³. After depreciation over 20 years, the energy cost for the manufacturing of the refrigeration is negligible. For fresh seafood the values are those for 1 day in wholesale storage in a unit three-fourths full holding 519 kg/m³ (*15*). ‖Refrigeration and depreciation only. ¶This column gives the sum of the last three columns and is the total to the point of reaching the consumer, not including transportation. Details of the calculations are available upon request.

Energy Accounting

The energy used to bring seafood to the table depends on much more than fishing. For the average food in 1963, processing took 33 percent, trade 16 percent, home preparation 30 percent, and transportation 3 to 9 percent of the total (*5*). Since the type of processing can have a large effect on the energy used in storage, transportation, and home preparation, it is important to look at the total energy use for individual foods. The energy cost of any process can be calculated in several ways. In process analysis, information about fuels and electricity used per kilogram of product is obtained directly from an industry. Then similar data are obtained from all the industry's suppliers, and so on until the inputs become insignificant. If this information is to be meaningful, it is important that companies representative of the whole industry are chosen. This method can take much time.

Another method, input-output analysis, uses information from the Census of Manufacturers published by the U.S. Department of Commerce. These publications give aggregated data on all materials used from paper clips to \$2-million purse seiners, by various classes of industries, such as the canned and cured seafood, frozen and fresh fish, or fluid milk industries. Herendeen and Bullard have converted this information into energy coefficients which, together with the price paid for the product, give the energy used to make it (*6*). These coefficients have the advantage of including all inputs from such things as logging the wood and mining the metals used to make machinery. Their aggregation and lack of detailed information are disadvantages.

We have used both methods to calculate the energy used for fishing and processing the fish. In addition, we have used a combination of the two methods; that is, the total fuel used in the process was found from the average price paid by the boat owner or processor, and the energy for the secondary inputs such as cans, machines, and fish nets was calculated from the price paid and Herendeen and Bullard's energy coefficients. Results from this combination of methods are given in Table 1. A comparison of process analysis and the combination with input/output for catching Maine herring and their processing as sardines is shown in Table 2. In the process analysis we have found the energy used to form the secondary input, but not to make the materials for it. The two methods agree for ice, probably because there is little energy involved in making the ice machine relative to the amount of electricity taken for the large quantity of ice used. The value for boat building and cans is much lower in our process analysis, since the large amount of energy used in mining and refining the steel is not included. Fish nets are put together by hand, so that the energy used to form them is negligible at least compared with fossil fuel consumption, but the mechanical energy used to form the synthetic twine (often imported from Japan) and produce it from basic chemicals is not. Considering the uncertainties involved in calculating the energies needed to make the basic materials, we feel that energy data giving average aggregated results, which include inputs for all starting materials, give the most satisfactory results at present for secondary inputs such as boats, nets, and cans. The results of this type of calculation are shown in Table 1.

Table 2. Inputs to seafood harvesting and processing. A large difference in some of the inputs in Table 2 is found because only the energy in the process itself is used in the process analysis, whereas all inputs are included in the input/output values.

Item	Process analysis (kcal/kg)	Fuels consumed with input/output analysis for secondary inputs (kcal/kg)
Herring harvesting (Maine)		
Fuel[a]	284	284
Ice[b]	95	90
Net (seine)[c]	1.3	64
Boatbuilding and repairs[d]	147	139
Salt[e]	17	
Herring canning (sardines)		
Fuel[f]	3,570	2,690
Electricity[f]	1,030	2,200
Fish	902	999
Oil[g]	467	860
Depreciation[h]	0	1,410
Cans[i]	445	2,890
Salt[e]	11	2,050
Paper[j]	750	662
Tuna harvesting		
Fuel[k]	14,600	5,690
Net (seine)[l]	~0	
Boatbuilding and repairs[m]	286	1,180
Man-hours[n]	8.8	
Tuna canning		
Fuel[o]	680	1,600
Electricity[o]	200	1,670
Fish	31,600	15,300
Oil[g]	440	530
Depreciation		880
Cans[p]	320	1,760
Salt[q]	11	1,300
Paper[r]	750	400

[a]Cost taken from Penn (*11*). [b]Cost to fishermen $11 per ton; 224,000 kcal/ton used for flake ice manufacture (*16*). [c]Manpower used only to put net together; 250 man-hours at 3000 kcal/day, on the basis of an 8-hour work day and 4-year net life (*17, 18*). [d]Sixty-foot purse seiner taking 32.7×10^6 kcal of fuel and electricity to build and one-half that for outfitting, with a 20-year depreciation (*19*). Repairs were due to manpower mainly. One gallon of Diesel fuel No. 2 was used to haul the ship out of water and return it, and 6 gallons of Diesel No. 2 was required to sandblast it. An overhaul was done annually (*20*). [e]Rock salt takes 90 kcal/kg for drying and crushing; 0.12 kg salt/kg fish used at factory and 0.19 kg/kg fish on boat (*21*). [f]Fuel was Bunker C (*22*). [g]Energy used to produce safflower oil in California (*23*). [h]Most Maine canning equipment is old and fully depreciated (*22*). [i]Energy to form, lacquer, and label a steel can holding 114 g of sardines assumed to be equal to that for a 341-g steel soup can (*24*). [j]The sardines' carton assumed to be similar to Makino and Berry's value for a cardboard shipping carton (*10*). [k]Estimated average value for the U.S. flag eastern Pacific purse seine fleet in 1975. [l]Net made by hand in Central America. Man-hours are not available but should be a negligible contribution. [m]Natural gas and electricity used for a $2-million purse seiner. Repairs said to be negligible (*25*). [n]Fifteen men working 213 days at 4200 kcal/day (*14, 17*). [o]Natural gas and electricity (*26*). [p]Value to form, lacquer, and label a 341-g soup can used (*24*). [q]The salt use was assumed to be similar to that for sardines and a negligible input. [r]Assumed to be the same as for sardines.

Harvesting Energy

Although more than half of the seafoods eaten in the United States are caught by ships under another flag, those with the processing listed in Table 1 are caught mainly by U.S. vessels. Domestic ships catch the fish sold to the fresh market.

In harvesting seafoods, there is a wide variation in energy used to produce a kilogram of protein, a ratio of 117 to 1 for lobsters relative to sardines. The value of 769 kcal per gram of protein for lobsters, the most energy-intensive seafood, compares with 800 kcal/g for feedlot beef (*1*) found by Pimentel and colleagues (Fig. 1). Catching shrimp also takes a great amount of energy: 598 kcal per gram of protein, much more than milk at 263 kcal/g; pork at 186 kcal/g; broilers at 149 kcal/g; or eggs at 132 kcal/g (*1*). Energy consumption for king salmon is similar to that for broiler chicken, while all the other seafoods consume less energy per kilogram of protein than do farm-animal products. Maine herring take amazingly little energy in harvesting: 6.58 kcal per gram of protein. This is less than that needed to grow a gram of incomplete protein from corn: 14.5 kcal/g; wheat: 13.8 kcal/g; or oats: 10.8 kcal/g (*1*). Maine herring are caught close to shore, sometimes with weirs, as was done by the Indians in colonial times. Tuna, the only example of fish caught by large, modern ships traveling into foreign waters, does not consume as much energy as might be expected. When fishing in the same area, large ships, although they catch more, take more energy than older, smaller ships per pound caught (*7*). The high values for lobster, shrimp, and king salmon reflect the overfishing of seafoods that have a high market price. Perch, one of the less popular fish, has one of the lowest energy inputs.

The ratios of energy output to input are compared with Wiviott and Mathews' value of 0.16 for 86-ton boats and 0.04 for 1947-ton ships catching a mixture of species (*7*), and with a value of 0.050 for fishing in the United Kingdom (*8*).

Processing

After processing, sardines are still one of the most economical seafoods in energy use (Table 2), but the cans add a great amount of energy, about two times the total energy taken to catch the fish in the can. Maine herring (sardines) are packed in crimped cans which do not have the lead seam found in most other cans. With sardines, this results in fish with five times less lead than found in those packed in a lead-seamed can (*9*). Berry and Makino have found that a 0.454-kg steel can has a free energy of 1000 kcal (*10*). Since fish are packed in smaller cans, 0.454 kg of fish would occupy more than one can. Our figures show that cans holding 0.454 kg of fish would take 1350 kcal for sardines, 1200 kcal for salmon, and 830 kcal for tuna. Fresh and frozen fish are close in processing energies, since energy used for their packaging and refrigeration is similar. The very high processing energy for "fresh" crabs seems surprising, but actually "fresh" crabs are steamed and packaged, and only 12 percent of the live weight is edible. All fish have greater energy use per pound of product after processing merely because the whole fish is not used. For filets about one-third of the fish is processed; for steaks more is processed, 42 to 72 percent (*11*). The relatively lower increase in energy on processing king salmon steaks reflects the fact that 72 percent of the fish is used (*11*). About 50 percent of the fish is used in canning. Table 1 shows that the addition of wholesale warehouse and retail store refrigeration adds 420 to 520 kcal/kg to frozen fish, assuming it is in wholesale refrigeration 3 months (Table 1). This is less than the energy taken to produce cans for a kilogram of fish. Roughly 1500 kcal would be needed for paper packaging according to our calculations. Fresh fish takes about 80 to 220 kcal/kg in wholesale and retail refrigeration. The total energy use depends, of course, on what is done in home, restaurant, or institutional preparation and on the transportation used. With the average food, home preparation adds a large percentage, around one-third of the total energy used (*5*). This energy can vary greatly, however. For instance, tuna can be eaten without cooking, cooked in the oven taking 4600 to 8500 kcal/hour, or cooked on top of the stove with very much less energy.

Discussion

There is a wide variation in the energy used to catch the various species of seafoods, comparable to the differences found between land-based animal-protein and vegetable-protein products. This variation in energy is not related to the nutritional content of the food. The amount of protein in seafoods varies by only a few percent (at most 10 percent) while the harvesting energy relative to protein output can vary by a factor of 117, when herring are compared to lobster. Lobster and shrimp, among the most energy-intensive, have the highest cholesterol content, so good nutrition would be well served through greater use of fish having lower harvesting energies.

A comparison of unprocessed seafoods with other protein sources shows that most fish provide more protein per kilocalorie input than farm animals. Surprisingly, herring, blue crabs, perch, and pink salmon in our calculation (Table 1) show better ratios than the irrigated field crop rice (*1*).

There is a large increase in energy input as a result of processing, regardless of the method, but to have a valid comparison of foods it is also necessary to know the total energy input through home use, which depends to a degree on the previous processing method.

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27. We thank David Pimentel (Cornell University), Erwin S. Penn (National Marine Fisheries Service), and Kirvin L. Knox (University of Connecticut) for helpful comments after reading the original manuscript and Dr. Regina Ziegler (Tufts University) for suggestions. We thank the Energy Research and Development Administration, Washington, D.C. 20545, for support of part of this work and its continuation through contract EC-77-S-024456.