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Popular in Europe, the blue mussel awaits discovery by the American public.

Blue Gold: Mariculture of the Edible Blue Mussel (*Mytilus edulis*)

C. GRAHAM HURLBURT and SARAH W. HURLBURT

INTRODUCTION

Mytilus edulis, commonly called the blue, or edible, mussel, is found in great abundance, growing wild, along the northern coast of the United States and Canada. This most desirable shellfish is almost unutilized in North America. Yet in Europe, where it is both a mainstay of life and a gourmet food, it is so popular that it is "farmed" commercially and the demand is greater than the supply. It is the same general size and shape of a soft-shelled (steamer) clam, but dark blue or brownish in color. It grows like an oyster; that is, not in the sand or mud but rather in clumps directly exposed to the ocean tides. The taste is a blend between an oyster and a clam, but, many say, better than both. The mussel is as rich in protein as T-bone steak, low in fat, an excellent source of minerals and vitamins, and can be eaten raw or prepared more than 100 different ways. Now that clams, oysters, lobsters, and finfish (as well as fishing employment) are becoming depleted in the United States, Americans will start to pay more attention to this delectable ocean food.

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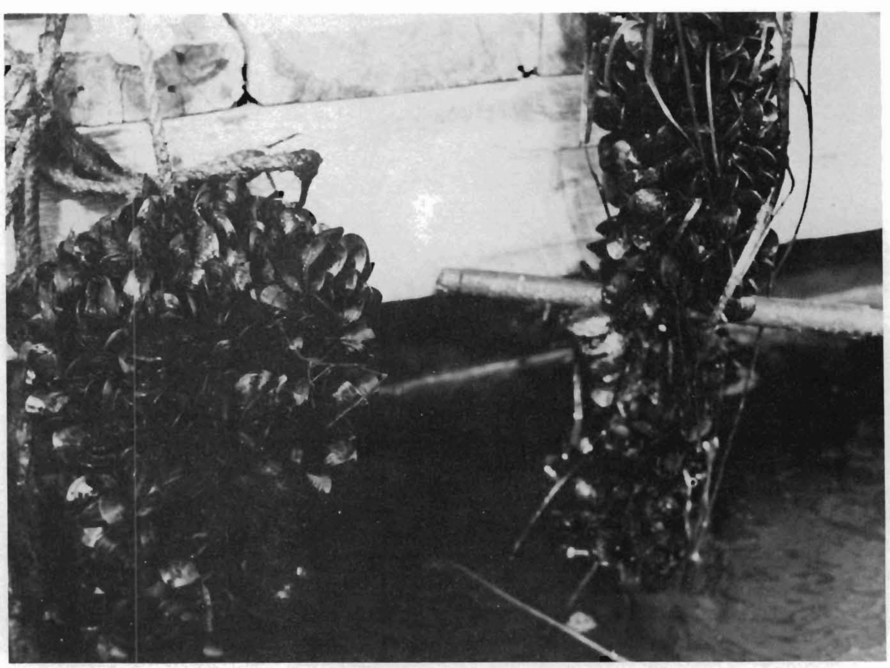
The mussel is a mollusk with two equal shells. The inside lining of these shells is pearly and iridescent. It is perfectly adapted to its tidal environment which explains why it is the most successful and abundant bivalve along the northern coasts. One of the major secrets to this success is its ability to attach itself to almost anything with its byssus. This attachment is so firmly moored that it can withstand the heaviest storm sea action. The mussel, like other bivalves, is a filter feeder. Its protective shells are tightly closed if exposed at low tide, but when covered with water they are held slightly open to allow the water to be drawn through the animal. It flows through the gills for respiration, and the food in the form of plankton (animal and vegetable organisms) and detritus (fine organic debris) is filtered into the mouth.

Enormous quantities of water pass through every mussel. An adult about 3 inches long will pass through itself as much as 10-15 gallons in a 24-hour period. An acre of wild mussels containing 2,000 bushels represents an astounding filtering machine. The apparently infinite supply of plankton organisms and detritus provides an almost inexhaustible supply of primary food which is rapidly and efficiently converted by the mussels to excellent flesh for human consumption.

This filter feeding explains why at infrequent times and in certain locations mussels should not be eaten. They and other bivalves can accumulate toxic substances when present in the water around the mollusks. Monitoring of the shellfish areas will prevent human consumption when accumulation rises above safe levels. Depuration (placing in sterilized sea water to remove bacterial substances) can similarly be implemented.

In northeast United States and Canada mussels spawn from April to Sep-



Mussel culture ropes, Duxbury, Mass. C. G. Hurlburt photo.

Workers wrapping mussels on ropes, Bay of Arosa, Spain. C. G. Hurlburt photo.

tember, and they are extremely fecund. The sexes are separate. The female sets adrift up to 25 million eggs at a single time. The males immediately release their sperm and the eggs are fertilized as they drift. When a great number of animals do this simultaneously, the surrounding water will appear milky. After fertilization, growth is extremely rapid. The young mussel passes through the swimming phase, maturing to the adult form rapidly. They settle down close together by attachment to objects and each other with their byssus. Their growth is very fast making them ideally suited to various culture techniques.

Why, then, don't Americans eat mussels? Their consumption in the United States is limited to a few gourmet restaurants and recent immigrants from Europe. The pilgrims in Plymouth recognized their value and it was stated by Governor William Bradford in 1622: "This bay (Plymouth, Duxbury, Kingston) is a most hopeful place. . .an abundance of muscels, the greatest and best we ever saw; . . ."

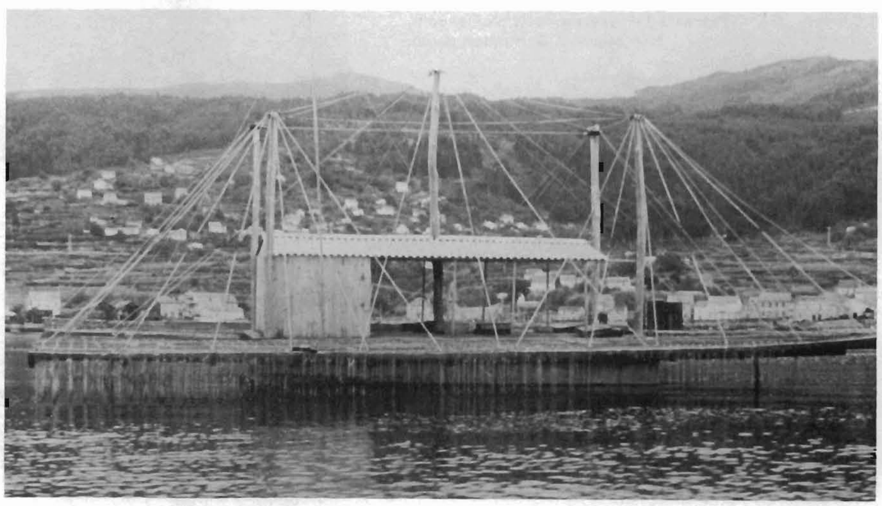
Most Americans have not been exposed to this seafood, probably because until recently other shellfish and finfish have been plentiful and inexpensive; but this is no longer the case. Over 80 percent of the fish purchased in the United States today is imported. Perhaps the name "mussel" is not pleasing to some.

Mariculture is the scientific term for "farming or cultivating the sea." Is a cultivated mussel better than a wild one? Probably yes, although they taste similar. Why? Because under controlled conditions they grow faster, can be harvested when they are fattest, and much more production can be achieved from a limited area of ocean. Cultured mussels are much more standard than wild ones. Also, it is a profitable industry—the fisherman-farmers make money, as well as the dealers, processors, markets, and restaurants.

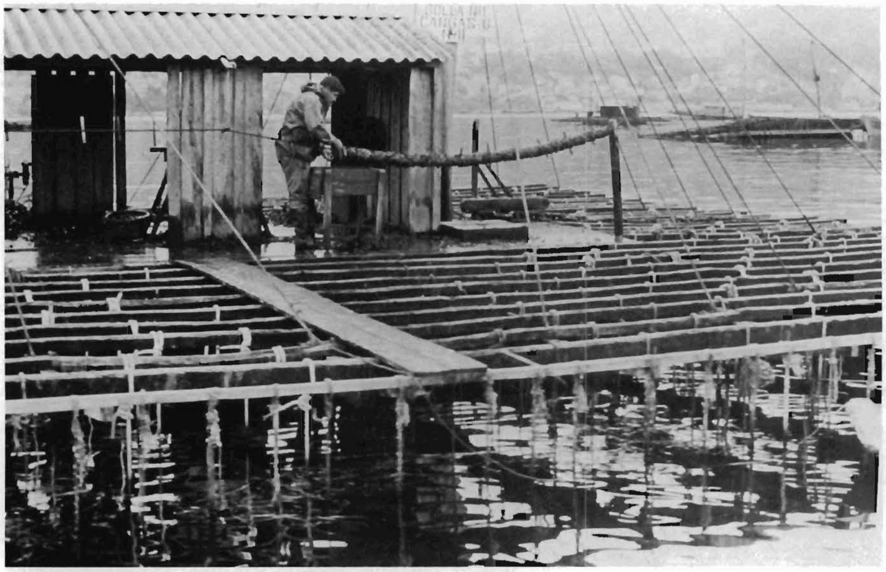
How is mussel mariculture accomplished in Europe and could the same be achieved in North America? To answer the latter first, we are certain that mussels could be farmed in North America just as they are in Europe, both in areas where they now grow wild and in many other waters where they are not now abundant. Problems—yes, but not insurmountable. In Europe they are grown in several different ways, depending on the geography of the coast and the velocity and heights of the tides. We shall describe three principal methods of mussel farming. These methods could be adapted to our coastal areas and the ones used would depend on local geographic and tidal conditions. There are a number of variations, but the three principal methods are: (1) the raft culture of Spain; (2) the pole culture of France; (3) and the bottom culture of The Netherlands.

NORTHWEST SPAIN—RAFT OR ROPE CULTURE IN THE GALICIAN BAYS

On the northwest Atlantic Coast of Spain at about the 42nd parallel lie five bays or rias. They extend far inland and the slope of the land to the water is reasonably steep, not unlike the coast of Maine and Canada. At the extreme they are 15 miles long, from 2 to 6 miles wide, and up to 200 feet deep with an average depth of 90 feet. They are protected from the full



Mussel raft, Bay of Vigo, Spain. C. G. Hurlburt photo.



Fisherman working on mussel raft, Bay of Vigo, Spain. C. G. Hurlburt photo.

Mussel depurator, Bay of Vigo, Spain. C. G. Hurlburt photo.

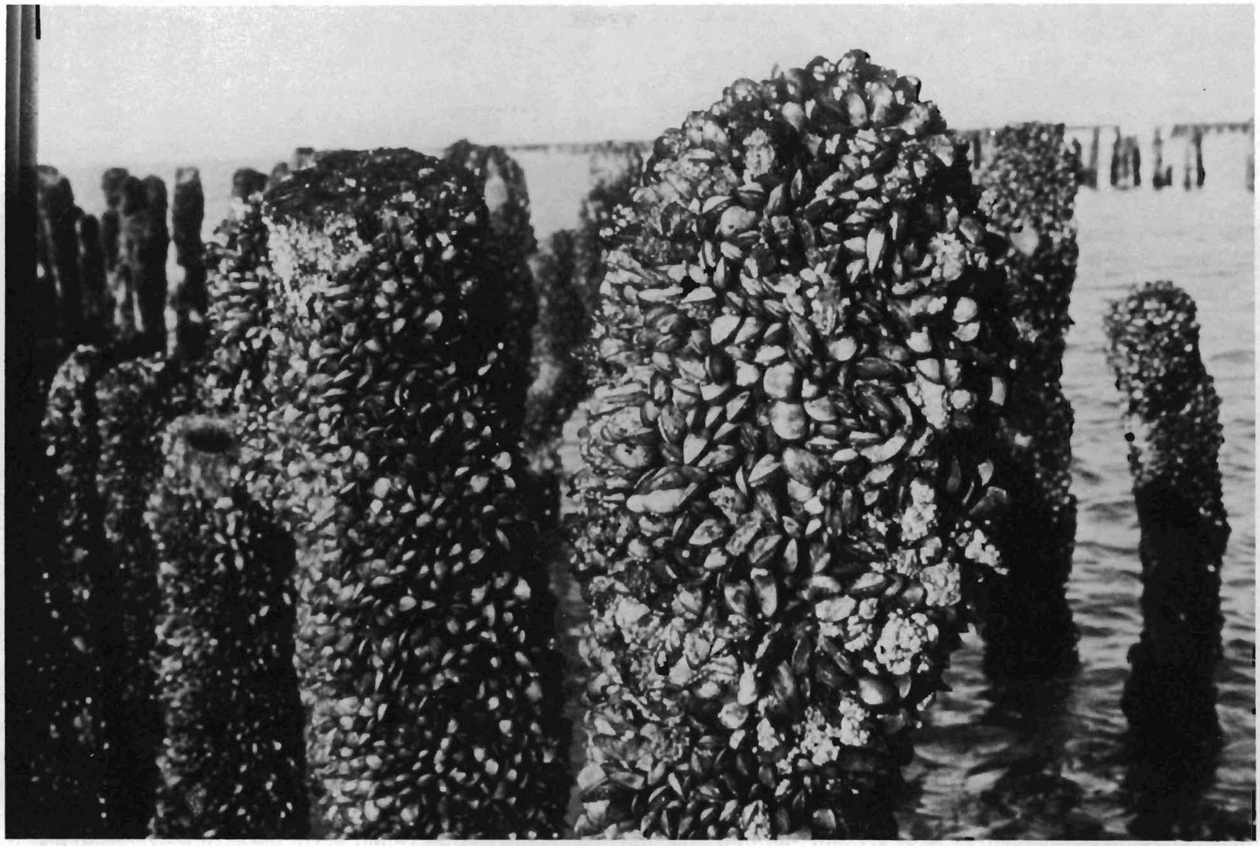
Processed mussel products, Pontevedra, Spain. C. G. Hurlburt photo.

force of the ocean by islands at their mouths. They have an average tidal rise and fall of about 10-12 feet. The water salinity is about 35 parts per thousand and the annual water temperature at the surface varies between 48° and 70°F. The mussel raft culture in this area is only about 30 years old.

The raft is a rather simple device. The first ones were made from the hulls of old fishing vessels. Later structures have from four to six concrete or steel floats or pontoons and a few new ones are constructed of Styrofoam[1] and fiberglass. On top of these floats is constructed a wooden (eucalyptus) lattice framework of 2-inch square timbers about 18 inches apart to which the ropes are fastened. The overall size of the rafts vary, but an average one might be 75 feet square and would support 700 ropes. The lattice frames are supported by stays running down from masts.

The rafts are anchored along the sides of the bays with large concrete moorings in about 35 feet of water at low tide. Each rope is about 30 feet long so it never touches the bottom. This eliminates the problem of starfish and other bottom predators. In the fall, clumps of young seed mussels (each about 0.25-inch long) are gathered from the rocks along the shore and wrapped upon the ropes with a water soluble rayon netting that dissolves within several days. During this time the mussels have attached themselves by their byssus to the ropes. The ropes are suspended from the rafts. In the spring the young mussel seed collects directly on bare ropes hanging from the rafts for that purpose. The mussels from the autumn seed mature to about

[1]Mention of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.



Mussels on bouchots, Bay of Aiguillon, France. C. G. Hurlburt photo.

3.5-4 inches in one year. These are the largest and fastest commercially-grown mussels in the world. Those from the spring seed take approximately 18 months to mature. The weight yield of meat to total live weight in the shell is 35-50 percent.

The mussels have to be thinned and transplanted several times during the cycle as their fast growth and bulk would cause them to fall off the ropes. The transplantation is accomplished by stripping the mussels off the ropes and winding them onto new ropes with netting or string. In some cases one rope will be stripped and two or three new ropes of mussels are made. The ropes are either 0.5 inch nylon or 1-inch local spart grass—all ropes being tarred. Every 1.5 feet a wooden stick about 1-foot long and 1-inch in diameter is inserted through the ropes to keep the mussels from sliding off.

A 30-foot rope produces over 250 pounds of live mussels annually and a 700-rope raft produces over 90 tons of mussels in the shell, or as much as 90,000 pounds of drained meat annually. One acre of water surface can support between three and five rafts. In an intensively cultivated area, 1 acre can produce more than 250,000 pounds of pure meat per year.

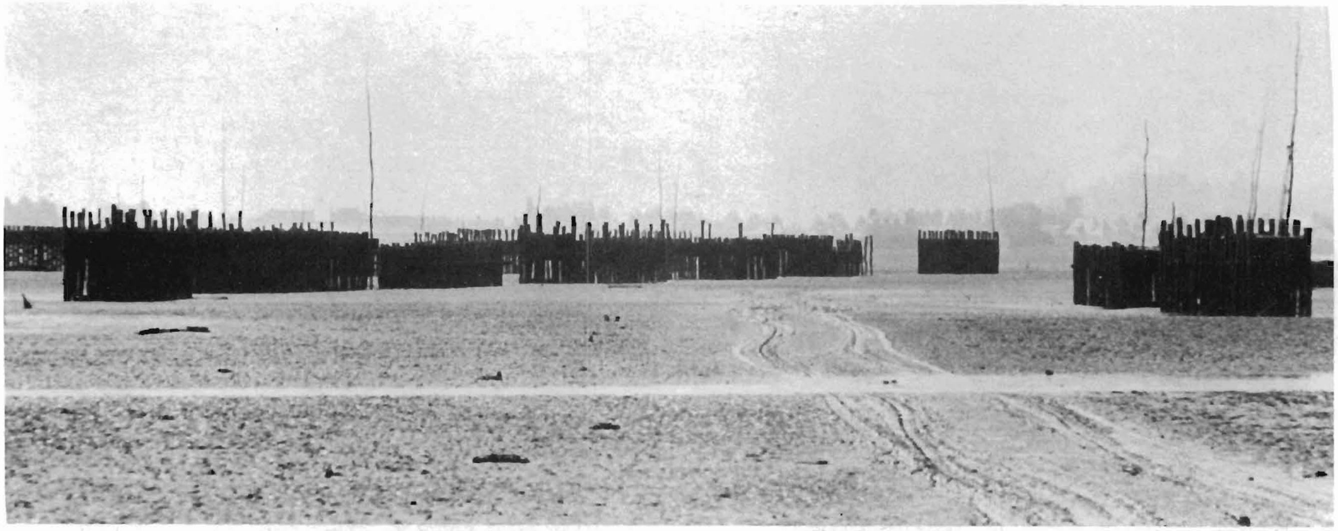
When mature, the mussel-laden ropes are hoisted aboard a workboat with a winch. A large wire-mesh basket is lowered under the rope before it is lifted. When on the workboat the rope is given a vigorous shake and the mussels fall off. Those of unmarketable size are wrapped onto new ropes for transplanting. The mussels that go to the canneries, and thus to be cooked, are transported directly to the factories. Those that will be sold fresh either in Spain or outside the country, must, by Spanish law, be depurated for 48 hours.

The depuration process is relatively simple. Seawater is pumped into large holding tanks and is measured for impurities. The proper amount of chlorine is added and allowed to evaporate, after which the water is pure. The mussels are placed on racks in tanks—usually shaded—and the purified water is slowly pumped over and through the racks for 48 hours. The mussels, now being certified clean, are placed in 15-kilogram (33-pound) mesh bags, sealed, tagged, and rinsed. After draining for 3 hours they can be shipped in unrefrigerated closed trucks for as long as 3 days.

Those mussels that go direct to the canneries are cooked in a conveyor steamer. They are shucked by hand and proceed down the production line for frying or to be covered by various sauces. The cans are sealed, cooked in a retort, labeled, and packed into shipping cases for worldwide distribution.

Spain is the world's largest producer of cultured mussels. The annual yield is in excess of 220,000 tons in the shell. Ninety-five percent of this is derived from the five Galician bays, where there are over 3,000 rafts. About 45 percent is canned, 5 percent frozen, and the remainder sold fresh. Of that sold fresh, about 25 percent is exported to France and Italy.

From two to four mussel rafts of average size can support a family well,



Mussel bouchots near Le Mont Saint-Michel, France. C. G. Hurlburt photo.

and generally this is a family enterprise, although there are some groups that own 20-30 rafts and hire employees. The water surface upon which the rafts float is leased from the government.

The depuration process is often a separate enterprise. The depurators buy the mussels from the growers and, in turn, sell them to the dealers. Sometimes the depurators purify the mussels for the growers (for a fee) who prefer to market their own. Some of the waste shells are ground and the high-calcium product is used to enrich the acid soil of farmland.

The Spanish mussel mariculture industry is innovative, uncomplicated, and profitable. It requires much hard work—and hard work is typical of fishing and fishermen worldwide.

ATLANTIC COAST OF FRANCE—POLE CULTURE

From the south Atlantic Coast of France, north through the coastal regions of Brittany and Normandy, mussel mariculture is accomplished by the pole or "bouchot" method. Here the coast is made up of long, gradually sloping beaches extending far out to sea. These beaches and the ocean floor are unprotected from the storms and other vagaries of nature. The salinity of the water varies between 29 and 34 parts per thousand depending on the season, and the water temperature fluctuates between 40° and 70°F. The tremendous tides are perhaps the most unusual feature of much of this coastline. In some northern areas there is at times a difference of about 50 feet between high and low water. This has both advantages and disadvantages for the mussel growers.

At low tide the ocean floor (beach) is bare sand or mud for many miles. In the southern regions where the tidal fluctuations are not as severe, much of the pole mariculture is conducted by boat and the bottom of the poles is seldom exposed to the air. The oak poles, about 8 inches in diameter, are driven into the ocean floor and the top 5 feet of the poles, exposed at low tide, is where the culture takes place. At low tide the fishermen tend the poles by boat. The poles are placed in long rows. They are about 3 feet apart and there is about 12 feet between the rows.

In the northern regions where the tidal differences are the greatest, the 12-foot oak poles are driven into the sand, leaving 6 or 7 feet above the sand. The bottom 1-foot of the pole is wrapped with a smooth plastic to discourage starfish, crabs, and other natural enemies. In this region at low tide the mariculture is conducted on foot. The fishermen—in tractors, on horse or oxcarts, and even on bicycles—ride out for miles to their "bouchots."

The pole method of mariculture in France was accidentally discovered in the mid-13th century. The principle involved has remained virtually unchanged since that time. An Irish sailor named Walton was shipwrecked and put ashore at Esnandes near La Rochelle in southwest France. He sank some poles into the ocean mud and stretched nets between them to catch sea birds for food. He quickly observed that mussels in great abundance grew on the poles, and thus began the "bouchot" system of mussel mariculture. In the Bay of Aiguillon where Walton came ashore there are now over 2.5 million poles—more than 50,000 rows of 50 poles each. In total, along the French coastline today there are about 700 miles of these rows of mussel poles.

Whether the poles are tended by boat as in the south, or on foot or cart as in the north, the system is very much the same with one exception: in the south where the tides are more gradual the seed is gathered naturally on ropes laid out for that purpose near areas of natural mussel beds. Within several weeks the natural seed mussels have attached themselves to the ropes and are ready for transplant to the poles. The seed ropes for the north must also come from the southern region as the great tidal velocity of the north prevents any natural local seed setting.

In both regions, however, after the seed stock is gathered on the ropes it is wrapped around the poles. The mussels grow, multiply, and rapidly fill the entire post, and soon grow several layers thick; at this time they must be thinned out by the fisherman who pulls off the outer layers and places them in long plastic net tubes (about 6 feet long, 6 inches in diameter). These flexible mesh cylinders are then wrapped around bare poles to start the process again. It takes from 12 to 18 months to have a mussel of marketable size (about 3 inches long).

After they are harvested—either by boat or on foot—the clumps are broken apart, washed, and separated for size. The marketable ones are placed in 20-kilogram (44-pound) burlap sacks—all to be sold fresh in France. There is no mandatory depuration in France, and few mussels are subjected to this process as they are grown in the clean open ocean. The mussel farming areas are constantly monitored by the French Government. If found to be polluted, they are closed until the situation corrects itself.

Those who work the "bouchots" by foot, ox cart, tractor, or little flat-bottomed mud boats called acon, miles out on the flats near Le Mont Saint-Michel, must be ever conscious to get to the mainland before the tremendous tidal bore surges toward them. As in Spain, the Government of France leases the mussel growing areas to the farmers. Most of the "bouchots" are conducted as a family enterprise with an average count of from 15,000 to 20,000 poles. A few of the largest farmers may have as many as 75,000 poles. One pole will yield about 20-25 pounds of live mussels per year, or about 10 pounds of meat. One acre will yield about 5 tons of live mussels, or over 4,000 pounds of meat annually. France produces over 50,000 tons of live mussels annually and all are sold fresh. In fact, the great demand in France for live mussels means that an amount almost equal to domestic production is imported fresh from neighboring coastal countries each year.

THE NETHERLANDS—BOTTOM CULTURE

The third and final method of mussel mariculture we will describe is bottom culture as practiced in The Netherlands. This method of farming the sea is closest to natural growth of wild mussels, but the harvesting, cleaning, and storage is and will be more highly mechanized. Mussel farming has existed for more than 300 years in The Netherlands. This mariculture is accomplished on the bottom of the shallow, partially diked, or enclosed seas. The mussel farmers here also lease their culture plots from the government.

The wild mussel seed is dredged up by boat from natural growth areas when it is from 0.33- to 0.5-inch long. It is then transplanted to the farmers' culture plots at depths of from 10 to 20 feet. These seed mussels mature to their marketable size of approximately 3 inches in about twenty months.

Most Dutch mussels are grown in the Waddenzee. This sea is on The Netherlands' northwest coast and is protected from the North Sea by encircling islands. The Waddenzee has a muddy bottom and when the mature mussels are mechanically dredged they ingest sufficient silt to make them undesirable. So they are taken down the full length of the Dutch Coast to the Rhine estuary near the Belgian border. Here they are deposited on the hard, sandy bottom of the bay where they cleanse themselves of the silt in the clean tidal water. They are stored here until they have regained their strength and/or until market conditions are favorable.

Dutch mussel growers now produce in excess of 100,000 tons of mussels annually. This, at 30 percent yield, makes over 30,000 tons of clear meat. Eighty percent of the production is sold fresh—most being exported to France and Belgium; the remaining 20 percent is processed into cans and jars for worldwide distribution. With the bottom culture method the Dutch farmers can produce approximately 25 tons of

Fisherman with seed mussels ready to transplant onto bouchot, Charron, France. C. G. Hurlburt photo.

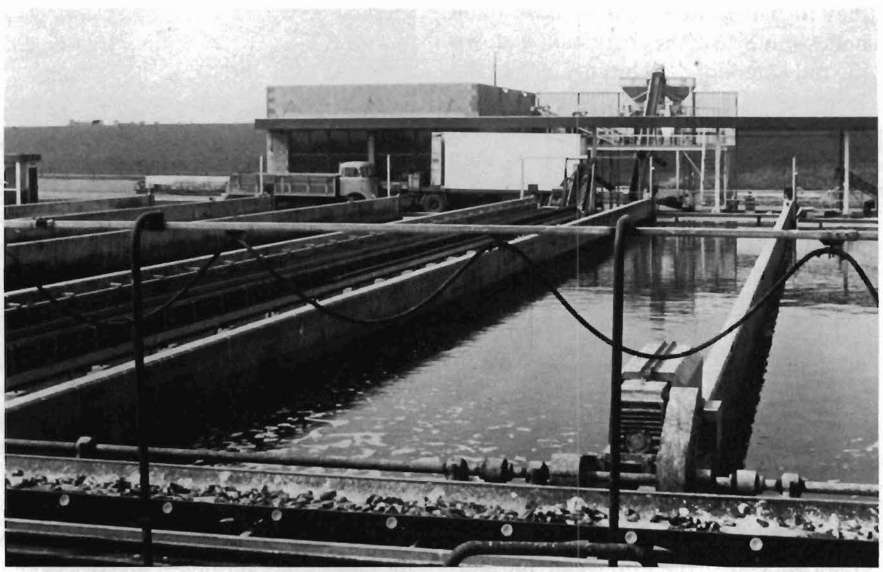
live mussels per acre annually, or about 15,000 pounds of clear meat per acre.

The mussel farmers of The Netherlands are now facing a serious, and peculiarly unique problem. The mussel cleansing areas in the south will be diked before 1980, thereby rendering useless the Rhine estuary as a mussel production and storage area.

To preserve this most valued industry the Dutch Government has developed a new, highly mechanized method for cleansing and storage of mussels.

Mussel fisherman thinning bouchot, Charron, France. C. G. Hurlburt photo.

Mussel fisherman going to work at low tide, Le Vivier-sur-Mer, France. C. G. Hurlburt photo.



Mussel experimental station and processing area, Isle of Texel, The Netherlands. C. G. Hurlburt photo.

Briefly, this involves bringing clean seawater into large tanks where the sediment settles out. This water is then pumped over and through the mussels stored in large concrete holding basins. This is similar to the depuration process used in Spain described above but is not necessarily for purification. The mussels are mechanically conveyed to a scrubbing machine which separates them and cleans the unwanted debris from their shells. From this point they are conveyed to a weighing and bagging area, and are ready for shipment.

The government mussel experimental processing station is located on the Isle of Texel, which separates the North Sea from the Waddenzee. It is now able to cleanse and process 5 percent of the Waddenzee production. In time it is planned that individual mussel processors will have their own storage and cleansing plants to service the mussel fishermen of the Waddenzee. This will insure a steady supply of an excellent product to the growing marketplace.

The Dutch process from seed to market is highly mechanized and for this reason their mussels are very good competitors. This high degree of mechanization however has certain drawbacks. An important one involves the amount of rough handling of the live mussel. This "shock" makes the mussel less durable, particularly pertaining to the live transport time. The mussel experiment station on the Isle of Texel is working to alleviate this condition.

We have explained briefly three methods of growing a very desirable high-protein food product. These have evolved into big and profitable industries, actually creating large quantities of meat and significant employment. It is reasonable to say that 1 acre of grazing land can produce 300 pounds of clear boneless beef meat. We can compare that to 4,000 pounds of clear mussel meat in France; 15,000 pounds in The Netherlands; up to 300,000 pounds in Spain.

What are the problems or opportunities we might encounter in trying to develop a similar industry in North America or elsewhere?

(1) A marketing problem (which we feel can be easily overcome, particularly at this time).
(2) A "real estate" problem (being able to obtain or lease saltwater rights for "farming").
(3) Perhaps government "seed money" to help initiate the industry and resultant employment.
(4) Education for the grower, the ultimate consumer, and all those in between.
(5) Development of mechanization to fit the various types of mariculture.
(6) Pursuit and completion of economic feasibility studies.

In North America, mussels (*Mytilus edulis*) grow wild in the tidal and intertidal zones from the Arctic Ocean to Cape Hatteras on the East Coast and from the Arctic Ocean to San Francisco on the West Coast. Where they grow wild in great abundance it is reasonable to assume they could also be cultivated. Where they do not grow in abundance in the wild state, experience in Europe and elsewhere would lend credence to the fact that they could be farmed successfully in many regions.

Mussels that grow completely underwater mature faster than those that are exposed twice a day to the air. This would account for the larger per-acre annual yield obtained in Holland as compared to France, even though the mussels in France (which are exposed at low tide to the air) are grown cubically, and those in Holland (with little or no exposure to the air) are grown on a plane, or flat on the seabed. This would also partially account for the tremendous yields per acre produced in Spain where the mussels are both grown cubically and are always submerged. For that reason alone it would appear wise for those contemplating mussel culture in the United States, Canada, or elsewhere to strongly consider cubic and totally submerged farming, whether it is by the raft-hanging rope method or otherwise. Like other forms of farming it is obvious that the larger the scale of operation, the more economical it is.

The mussel as a human food is certainly one of the most efficient producers of edible flesh. It has been estimated that there is a 90 percent energy loss in the conversion of food into meat. Mussels are very close to the beginning of the food chain, and therefore there is actually little waste as compared to finfish, beef, and other flesh foods. Big fish have eaten little fish, who have eaten smaller fish, etc.—each time a 90 percent loss of energy. It takes about 8 pounds of feed to produce 1 pound of edible beef. A steer consumes 21 pounds of protein in order to produce 1 pound of protein.

Imagine—43 billion pounds of flesh meat per year from an area of water the size of Cape Cod Bay, which is approximately 18 miles by 15 miles. At the annual mussel production rates now being achieved in northwest Spain this is theoretically possible. This much high-protein meat would provide every living person in the United States with 1 ton of meat per year (average 1972 beef consumption was 116 pounds per person), or every man, woman, and child on earth with 10 pounds of nutritious meat per year! In less than 300 square miles! It is technically feasible now.

The meat of the mussel is extremely nutritious. Studies reveal that the edible blue mussel not only has the same kind of nutrients as other shellfish, but has them in greater quantity and quality. Of the five species of common shellfish listed below, the mussel ranks first, second, and third respectively in the yield of carbohydrate, fat, and protein. It is undisputedly superior in the total production of nutrients and food fuel value.

Comparative composition and fuel value of certain shellfish in percent[1].

	Sea mussel	Lobster	Long clam	Round clam	Oyster
Refuse	46.7	61.7	41.9	67.5	81.4
Water	44.9	30.7	49.9	28.0	16.1
Protein NX6.25	4.6	5.9	5.0	2.1	1.2
Fat	0.6	0.7	0.6	0.1	0.2
Carbohydrate	2.2	0.2	1.1	1.4	0.7
Ash	1.0	0.8	1.5	0.9	0.4
Total nutrients	8.4	7.6	8.2	4.5	2.5
Calories of fuel value/lb	150	141	136	68	41

[1]Data from Langworthy, C. F. 1905. Fish as Food.

Compared with beef (T-bone steak, choice), mussel meat is most attractive. This is well illustrated by the following nutritional audit taken from U.S. Department of Agriculture Handbook No. 8, *Composition of Foods* (December 1963).

3½ oz raw meat	Common blue mussel	T-bone steak (choice)
Calories	95	395
Protein	14.4 g	14.7 g
Fat	2.2 "	37.1 "
Carbohydrates	3.3 "	0 "
Calcium	88 mg	8 "
Phosphorus	236 "	135 "
Iron	3.4 "	2.2 "
Thiamin	0.16 "	0.06 "
Riboflavin	0.21 "	0.13 "

Mussels can be prepared from the fresh stage in countless different and attractive ways. They can be preserved by canning, freezing, drying, smoking, and pickling; all delicious! They can be readily processed into high-quality, nutritious protein concentrate, odorless and tasteless, which could be incorporated into new or familiar foods for protein starved, underdeveloped areas of the world.

Authors with mussel culture ropes, Duxbury, Mass. Leeds Hurlburt photo.

Regarding the palatability of mussel meat, it is tender, of high quality and—as attested to by hundreds—its flavor is superior to clams, equaling that of oysters. It is readily digestible and the proportion of nutrients supplied to the body is almost identical to those supplied by steamed beef which is considered to be highly digestible.

Therefore, one could draw the conclusion that mussel meat is highly desirable—it is most palatable, and could be now and in the future the cheapest, most nutritious, and most abundant of not only shellfish, but of any meat on the world market.

We believe the edible blue mussel can materially aid in solving the rapidly inflating world food crisis. This global protein deficiency is brought into focus when we realize that the world population growth has now reached a rate where population will double every 37 years.

As the late President John F. Kennedy said before the Food and Agriculture Organization of the United Nations in 1961:

> "A first responsibility of the human race is to see that its members have enough to eat. . .Nutritional problems are not peculiar to countries where food is scarce. Protein malnutrition is, in fact, a serious disease affecting nearly two-thirds of the world's population. There is, therefore, an urgent need for the exploitation of what is probably the major untapped source of food: products from seas and inland waters. . . Your part in the task that lies ahead, like that of other dedicated people in commerce, in laboratories, in factories, farms and fishing boats, is to recreate the miracle of the loaves and fishes. . .a miracle no less spiritual for being scientific."

We might add, it can be done and it will be done, practically and profitably. With one known exception the authors now have the first mussel culture ropes in place in North America. The early results appear encouraging.

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