Fishing for Markets

Regulation and Ocean Farming

Michael Markels Jr.

Although three-quarters of the Earth's surface is covered with water, most productive activities involve exploitation of land resources. A plan to fertilize the oceans and harvest the resulting exploding population of fish would face more than technical problems. A political and economic obstacle, the lack of private property rights, could be equally daunting.

Ocean farming of the Gulf Stream along the Atlantic Coast of the United States could increase that area's phytoplankton, the base of the food chain, by a factor of about one thousand—to a billion tons per year by bringing the productivity up to the level that occurs naturally off the coast of Peru. That could increase the fish catch by a factor of 400—from 125,000 to 50 million tons per year. At 40¢ a pound for fish, that would be worth $40 billion per year. On a sustained basis, such a revolution in ocean agriculture could provide half a million new jobs, revitalize a declining industry, and generate high-quality protein and industrial fish meal for domestic consumption and export. The atmospheric carbon dioxide absorbed initially by the oceans could exceed carbon dioxide production from the burning of fossil fuels in the United States.

All the ocean farming would take place within America's 200-mile exclusive economic zone, and all the impact would be within U.S. waters, assuring that the benefits from the increased fish production would be reaped by our fishing industry. The cost (principally for fertilizer) of the productivity enhancement program is estimated to be about $100 million per year. The program would provide over $400 million per year in additional tax revenues at the state and national levels. When the benefits from ocean farming have been demonstrated, they can be applied to the other U.S. coasts and to similar ocean currents around the world.

But this plan or any similar plan to make use of the sea's resources would run into a fundamental problem. Since the ocean is a commons—that is, an area not owned by specific individuals or entrepreneurs—investment by private industry may not be possible. Some kind of private property rights need to be created so that those who bear the costs of farming can reap the rewards. The only other option is for the U.S. government, the "owner" of the resource, to become the ocean farmer. This is a role ill suited to government and the political process—especially under the current political climate of cost-cutting and decentralizing.

Background

The earliest history of the human race shows

Michael Markels Jr. is the founder of a national environmental company, Versar Inc., as well as the founder, president and CEO of a new company, Ocean Farming Inc., organized to commercialize his new, patented technology for enhancing the productivity of the oceans.

hunter-gatherers taking what the land produced but remaining a part of the natural scene, rather than changing it to human purposes. Some 10,000 years ago in the Middle East that changed, as men domesticated wild animals, moving herds to the best pastures with the changing seasons. That trend continued with the domestication of the horse in the arid regions of western Asia.

Then about 5,500 years ago a new invention swept the world: the moldboard plough. That plough increased the productivity of the farmer by a factor of seven. It also changed man's way of looking at the land from one of passive acceptance to one of active intervention. Man began to plant favored crops, rather than accepting what had always grown there. Since the hunter-gatherer stage, farming output has increased about 2,000 times.

A key to the successful cultivation of land was the development of the legal and economic institution of private property. When particular individuals who put their sweat or capital into land were allowed to reap the benefits of production, it gave them an incentive to seek greater output. The failure of collective farms in the former Soviet Union on some of the most fertile land in the world indicates the importance of property arrangements.

While the transition to a private property rights regime occurred on land, it has hardly begun on the three quarters of the earth's surface covered by oceans. Oceans have been thought of as so vast as to be beyond improvement by human efforts, and fish so numerous that men have only to find them. But concepts of the ocean are starting to change as the consequences of overfishing become obvious to all. The time is ripe to apply the concept of farming to the ocean for a return similar to what has been achieved on land.

The Ocean

The fishermen of the world have known for many years that there is great variation in the productive potential of the different areas of the oceans. Sixty percent of all life in the ocean occurs in 2 percent of the ocean surface. It is easy to spot the difference. For most of the ocean, one can see 150 feet through the water. In the productive zones, such as off the coast of Peru, one can see only a few feet because the living matter is so dense. The productive zones are fecund principally because of their richness in iron, trace metals, nitrogen, and phosphorous.

The ocean differs from the land in several respects: (1) there is never a drought; (2) it moves; and (3) it mixes both vertically and horizontally. The first difference means that ocean farmers need only add minor constituents to produce results. The second difference means that where nutrients are added and where fish are harvested likely will be many hundreds of miles apart. The third difference means that farming must be done in the open ocean on a large scale.

Another important attribute of the sea for prospective farmers is the large effect of the density of biomass on the efficiency of the transfer of food between the levels of the trophic, or food, chain. Nutrient-poor ocean waters have such a low concentration of phytoplankton that they support almost no fish, because the fish must expend more energy to graze on the phytoplankton than the phytoplankton provides. In nutrient-rich water, however, all levels of the trophic chain have their next meal immediately at hand.

The loss per trophic chain level can be as high as about 90 percent and as low as about 10 percent. That is to say, in some cases, the energy that a fish must expend to secure food might offset 90 percent of the energy gained from the food. The fish therefore only gains 10 percent for its efforts. In such cases, the ratio of pounds of fish to pounds of phytoplankton is about one per 100. In richer waters, however, only a small effort is required to secure food. The gain, once the energy expenditure is accounted for, is 90 percent. Here the ratio of pounds of fish to pounds of phytoplankton is about 100. This difference in ratios produces the dramatic differences in fish stocks of about 1,000 between the nutrient-poor El Niño years and the verdant upwelling years.

Ocean Farming

What are the basic principles on which ocean farming rests? Scientists use what are called "Redfield ratios" to describe the response of the ocean to critical nutrients. In theory, under perfect laboratory conditions, one pound of available iron can lead to the production of 100,000 pounds of biomass at the level of plankton and other lower plant life. But to the iron must be added phosphate, a float material to keep the fertilizer in the photic zone, that is, the top 100 feet of ocean surface in which sunlight penetrates, contributing to the production of sea life. Also required is a seed material of phytoplankton to fix the nitrogen. Use of that material reduces the productivity of one pound of fertilizer to about 10,000 pounds of biomass. Another factor also reduces maximum results. The ocean is not a controlled, uniform system. This fact cuts the productivity of fertilizer more, conservatively figuring, to 4,000 pounds of biomass per pound of fertilizer in the Gulf Stream.

Another way to express the productivity is in terms of output per acre of ocean surface. Nutrient-rich ocean can produce 40 tons of biomass per acre per year. This is the same level of productivity as for sugar cane cultivation on land: 25,600 tons per square mile per year. And nutrient-rich ocean should be more productive than land.

On land, farming, planting, and fertilizing are done in the spring, and harvesting in the fall. In the ocean, under ideal conditions, the algae and phytoplankton double every day or two, increasing by 20 to 30 times in about five days. The zooplankton graze on the algae, the bait fish eat the zooplankton, and so on up the food chain to the large mammals and predator fish whose life cycles approach decades. Since the Gulf Stream flows about four miles per hour, fertilization at one location will produce results in another. The delay time of four days translates into 400 miles at four miles per hour. For the Gulf Stream, that means that fertilizing off of Key West would yield improved fishing off of north Florida, with the larger fish coming in off of Georgia, the Carolinas, and Virginia and into the North Atlantic. Depending on how the nutrients are added, the improved "grazing" conditions for economically important species of fish and invertebrates could continue for thousands of miles of the Gulf Stream—as far as Maine—producing more highly migratory species such as tuna.

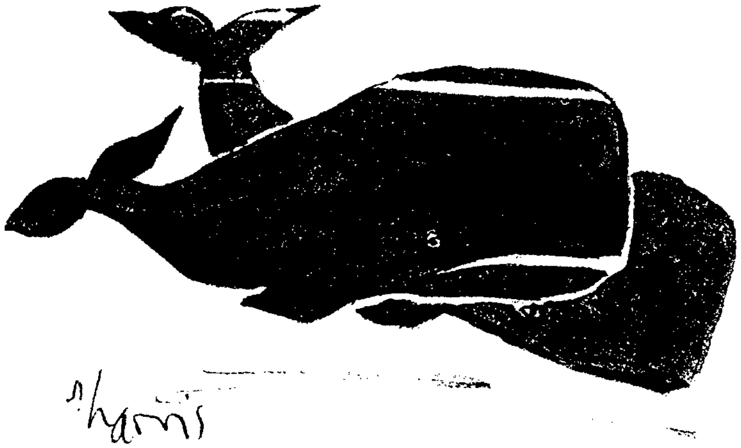
The Gulf Stream flow is very complex, developing vortices and eddies on both sides of its core. It is profoundly affected by prevailing atmospheric driving forces and tides. It is likely that with appropriately sited nutrient additions to the system, the marine phytoplankton will respond quickly, with the rest of the life along the chain following later. One cannot presently forecast which species in the Gulf Stream ecosystem will prosper, nor which will decline; however, one can speculate on the basis of experience elsewhere. For example, off of Somalia, the annual fish-catch cycle is profoundly influenced by the rapid, seasonal upwellings of nutrient-rich water in that sector of the Indian Ocean which is dominated by the atmospheric monsoon. Major harvesting occurs there for a sardine-like species that grazes on the phyto- and zooplankton blooms triggered each year by the monsoon-driven upwellings. The upwellings off of Peru also provide a major catch of filter feeders: the anchovetta. Smaller tonnages of higher trophic-level fish are also caught, including swordfish and tuna attracted by the high concentrations of bait fish, on which they feed.

There is another likely benefit resulting from a massive increase in life in the seas: a reduction in atmospheric CO_2, which has been linked to environmental problems. The United States produces about 1,340 million tons of CO_2 per year from burning fossil fuels such as gas, coal, and oil. One ton of fertilizer in the oceans can produce 4,000 tons of biomass, which initially removes 5,500 tons of CO_2 from the ocean. Therefore, to cancel out America's fossil fuel production of CO_2 would initially require about 250,000 tons of fertilizer. That can be done by fertilizing about 53,000 square miles of ocean in the temperate region: an area of the Gulf Stream about 100 miles wide and 530 miles long, about the same size as the Chesapeake Bay. The Gulf Stream is about 200 miles wide and 1,000 miles long, about four times the area of the Chesapeake Bay.

Fish Production

Phytoplankton constitutes the base of the food chain. Many oceanographers believe that, on average, each trophic, or food chain, level results in a 90 percent loss of energy from the level below. Therefore, moving up from phytoplankton four trophic levels, we find that tuna, for example, only receives one 10,000th the amount of energy and nutrients from the lowest level. (This explains why much of the ocean is devoid of life.) On this basis, one billion tons of phytoplankton produces 100,000 tons of fish at the top of the food chain. Under such conditions, the ocean farming enterprise would fail in most cases, since the additional fish caught are worth less than the cost of adding the nutrients.

But the rule of thumb used by many oceanographers only applies to the nutrient-poor open ocean, where the phytoplankton are so dispersed that the grazers can barely get enough energy to



"I'm strictly a squid and seaweed eater. Whenever I have plankton, I'm hungry an hour later."

survive until their next meal. In the highly productive conditions of the upwellings, other trophic-level efficiencies apply.

As noted above, scientists estimate that 60 percent of all life in the ocean arises from 2 percent of the ocean surface. Therefore, if all of the ocean was as fertile as this 2 percent, there would be 30 times (0.6/0.02) the present ocean life. If all the ocean was like the 98 percent nutrient-poor zone, there would be 0.41 times (0.4/0.98) the present ocean life. The ratio of the fertile to the nutrient-poor areas is therefore 30/.41, or 73.5, assuming a linear relation between phytoplankton and fish catch. That is, if we fertilize a nutrient-poor region like the Gulf Stream between Key West and the Outer Banks to conditions such as exist off of Peru, we should get a catch 73.5 times greater than normal. The Gulf Stream catch was 125,000 tons in 1993—a value of $161 million. With fertilization, the catch should be over 9 million tons (73.5 X 125,000)—a value of about $12 billion if the price per pound were to remain constant.

A recent paper by D. Pauly and V. Christensen in the March 1995 issue of *Nature* offers a method of measuring productivity, the "primary production ratio," including catches and discards. The ratio consists of the pounds of fish caught per pound of phytoplankton produced. The open ocean value is 1.8/100, that is, 1.8 pounds of fish per 100 pounds of phytoplankton. But the value for fertile zones such as the one off of Peru's coast is higher: 25.1/100, or 25.1 pounds of fish per 100 pounds of phytoplankton. The highest value for nontropical shelves is 35.3/100, or 35.3 pounds of fish per 100 pounds of phytoplankton. That figure is for the Georges Bank before the fish population was decimated by overharvesting.

Using the low open-ocean ratio of 1.8 pounds of fish per 100 pounds of phytoplankton and the current annual Gulf Stream catch of 125,000 tons, the estimate of the current level of phytoplankton production is about 7 million tons for the Gulf Stream from Key West, Florida to the Outer Banks of North Carolina. (That figure is only about 0.7 percent of the one billion tons that could be expected from fertilization, which would be 143 times normal production.) Upon reaching the higher density of phytoplankton, fish at every level of the food chain expend much less energy to get a meal. The fishermen also expend much less effort to obtain their catches. Assuming the higher production of fish found off of Peru, at the level of 25.1 pounds of fish per 100,000 pounds of phytoplankton, the catch for the upwelling situation increases by another factor of 14 (25.1 lbs./1.8 lbs. = 14). The combined increase in fish production would be the increase expected from more fertile waters times the increase due to plankton production (14 X 143 = 2,000). Therefore, we should catch 250 million tons (2,000 X 125,000 tons) of fish with fertilization. We can get the same answer by multiplying the one billion tons of phytoplankton by 0.25 tons of fish per ton of phytoplankton.

Some confirmation of these estimates can be obtained from data on the effects of the El Niño event of 1982-83 off the coast of Peru. Wind shifts dampened upwelling of nutrients from the ocean, radically reducing production of higher forms of sea life to levels closer to those of the less fertile Gulf Stream. As a result of El Niño, the anchovetta catch off of Peru was reduced to 1/600th of its normal value. Since the effort expended by fishermen to take in even that meager catch went up per ton of catch, it is not unreasonable to assume that the fish stock actually went down by a factor of about 1,000. This shows that a factor change of 2,000, as was found above, is of a similar magnitude to changes found in the real world. It is interesting to note that the large changes in productivity at all levels of the food chain took place in a time frame of a year or two, which indicates the likelihood of a similarly rapid response to ocean farming in the Gulf Stream.

The estimate of a Gulf Stream catch 2,000 times current levels, to 250 million tons, is very large indeed. After all, the total world fish catch is only 100 million tons per year. But even if one assumes that the increase is only one-fifth of the estimated amount, that still means around 50 million tons per year from Gulf Stream fertilization—and that only after some years so that the fish stocks have an opportunity to adjust to the increase in the base of the food chain.

The high productivity per pound of feed can be understood by contrasting some farming ratios. The production of a pound of beef cattle takes 10 pounds or more of feed; for chickens it is about 5 pounds of feed; for turkeys, about 3.5 pounds of feed; and for trout in an engineered fish farm, 1.1 pounds of feed. The conversion efficiency of the fish comes from the fact that fish do not expend energy to keep warm, and since their next meal is only inches away, they expend little energy in capturing it.

The value of the catch under the three sets of assumptions about the productivity of the ocean thus would be as follows:

1. One can assume the rule of thumb level of productivity used by many oceanographers. In such a case, such a small increase in fish occurs that the increased value of fish catches is essentially zero;
2. One can assume that the nutrient-poor oceans could be made as fertile as the most fertile 2 percent. In such a case, the value increase, based on the same price per pound as the current South Atlantic catch, which is valued at $161 million, would be 73.5 times that amount, or a $12 billion increase; or
3. One can assume the best case, that fish production in the Gulf Stream rises to 250 million tons. Assuming an average value of 20¢ per pound, the increase in the value of the catch would be $100 billion.

I project an increased catch of 50 million tons per year, with a value of $40 billion at $40 per pound.

There are many uncertainties involved in ocean farming. But a saving aspect of such a project is that if there are problems, it can always be stopped. Within two weeks after the program is abandoned, all impact on the Atlantic Coast would cease, and in approximately one month all new global impact would cease as well. In spite of the low level of impact, there will always be those who take the view that anything that man does to change nature is bad no matter what. But we are dealing here with a system that is already broken. We can help to fix it by creating conditions that nature already provides elsewhere. We are irrigating the desert and making the desert bloom.

Fertilizer Production

Since sea life appears ultimately capable of processing nutrient materials regardless of their chemical makeup or form as long as those materials remain in the photic zone where sunlight penetrates, the least expensive, most readily assimilable forms of fertilizer materials could be used. It appears that many present-day nontoxic waste streams offer possibilities to produce nutrient constituents at low cost, with concurrent benefits to recycling programs. Nutrients will be effective only if they are released in the top 100 feet of the ocean surface, the photic zone. Therefore, it would probably be useful to hitch the fertilizer to a float material, like peanut hulls or ground corncobs. (A series of patents are being issued to the author covering this technology, and a new company, Ocean Farming Inc., has been organized to carry out the commercialization of ocean farming.)

If fertilizer costs $200 to $400 per ton when applied to the ocean surface, the estimated annual cost is $50 million to $100 million for the application of 250,000 tons. A $100 million per year experiment fertilizing 53,000 square miles of the Gulf Stream may not be the minimum-size experiment needed to demonstrate the possibilities of open ocean farming. As the tons of fertilizer applied and the area are both reduced, we will approach the point at which the high density of phytoplankton and fish required to get the high trophic efficiencies will not be achieved. We do not know where this changeover occurs, but it is probably a large area because of the high energy of the Gulf Stream flow and the attendant rapid mixing at the boundaries.

Economic Impact

Production of an additional 50 million tons of fish (worth about $40 billion) from fertilizing the Gulf Stream along the Atlantic Coast would have a significant impact on our fishing industry. The increase in both catch size and value would be about 10 times the total 1993 values for the United States and about one half the total 1992 world catch. If one new job is created for each $80,000 increase in sales, 500,000 new jobs could result over a five- to 10-year period. The $40 billion net increase would provide more than $400 million in additional tax revenues, while reducing unemployment payments at the national and state levels—which would more than compensate for the projected $100 million cost.

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The above estimates are for Gulf Stream farming only. Fertilizing should also produce enhanced fishing productivity for the rest of the Atlantic seaboard, the Gulf of Mexico, and the Pacific, especially off of California. There are also other coastal areas around the world where the technology could be applied with similar results.

Investment in Enhancing Ocean Productivity

The technical problems are not the only ones facing would-be ocean farmers. Just as daunting will be the problems posed by the lack of property rights in the seas. The ocean is an economic "commons." Single individuals and firms do not have exclusive claim to portions of the sea's bounty. There is every incentive for any one fisherman to catch as many fish as possible. After all, if he does not, someone else will. If there is one fish left, it is to the individual fisherman's advantage to catch it. There is no incentive or advantage for him to invest in enhancing ocean productivity, since others who do not bear the costs of fertilizing the oceans will reap the rewards. Both aspects of the "commons" problem must be solved in order to enhance ocean resources.

It is now technologically possible to decimate any fishery within a year or two given the necessary effort, dedication, and perseverance. Once that has been achieved, the open "commons" approach to exploiting the resource can no longer be sustained. The fishery will always be overfished and the stock reduced to an uneconomic level. That has already happened in the Georges Bank of the United States and to the anchovetta off of Peru.

One method of dealing with the problem is to use government regulation. That has been tried in New England and many other fisheries with uniformly poor results. The method of regulation used often involves limiting access to fishing; limiting the technology applied to catching the fish; and limiting the pounds of fish that may be caught. It is always to the fisherman's advantage to ignore or circumvent the regulations, since he gets no return for fish left in the sea. Also, government regulators respond to political pressures and have no stake in maximizing the output of a resource.

The answer that has worked wonders on land is the introduction of private property. For the oceans, an imperfect version of property rights has taken the form of individual transferable quotas or ITQs. ITQs give the owner the right to a percentage of the allowable catch for a particular fishery, and hence a financial stake in its health and productivity. That approach is in operation in Australia and New Zealand, as well as selected U.S. fisheries.

The allowable catch is set by a government board or council and is therefore open to political pressures. The board itself and its members have no stake in the outcome of their decisions, and so are likely to set the allowable catch based on criteria other than maximizing output from the resource. The ITQs are distributed to the fish owners of record in the fishery, depending on prior catch levels and other criteria. ITQs are "owned" by the holder and are tradable, and therefore may be used as collateral for loans.

The ITQ approach has worked better than the commons approach. The ITQ "owner" has an incentive to join with others, perhaps with his local fishing council, to invest in the productivity of the resource by using ocean farming technology. Each individual council could levy a landing fee to be used to enhance the productivity, and hence structure the value, of the fishery resource.

That would permit the required return on investment. But such landing fees are not possible as the law is currently structured in the United States.

The only other way for investment to occur is for the current owner, the U.S. government, to make it. While that may have been possible in the past, there is little enthusiasm in Congress for such expenditures at this time. That may not be a disadvantage, since the government does not have a history of operating productive resources like farms efficiently.

The most effective approach would then be to privatize the entire resource. The government could put all rights to the resource into two corporations, one for the Atlantic and one for the Pacific Coasts. Stock would be distributed to the fishermen, ITQ holders, and other stakeholders. The rest would be sold in a public offering. Once privatization is complete, federal regulation of fishery access and catches would be unnecessary and counterproductive. The corporations would compete for markets and would look for opportunities to export their technology and expertise worldwide. They would apply all available technology to maximize the return from their resources. The shares owned by the fishermen would become very valuable, resulting in a rapid return for the right to the depleted commons that the fishermen and everyone else gave up. The fishermen would then become independent contractors to the corporation and would have a stake in its success. They would, therefore, help to eliminate poaching and other activities that reduce the productivity of the resource.

Recommendation

One approach to the commercialization of the ocean farming technology is a three-phase program in the Gulf Stream.

- **Phase I.** Laboratory-scale (microcosm) studies would be conducted to determine the characteristics of the necessary fertilizer. The estimated cost is $200,000 over a period of one year.
- **Phase II.** Macrocosm-scale tests would be conducted in the Gulf Stream water, in one-acre test enclosures, open at the bottom, that restrict the movement of the ocean water to permit tests of 10 to 20 days. Such tests under open-ocean conditions will refine the fertilizer design and determine the magnitude of the resulting phytoplankton bloom. The estimated cost is $2 million over a period of one year.
- **Phase III.** A test of approximately 53,000 square miles of the Gulf Stream would be conducted to determine the response of fish life to the increase in phytoplankton growth in the open ocean from fertilization. Small changes in fertilizer design are expected based on these experiments, along with improved understanding of the optimum areas and concentrations of fertilizer application. The estimated cost is $100 million per year.

Since it is unlikely that the federal government will finance this project, some sort of privatization of the fisheries is required so that a return, perhaps from landing fees, could be used to provide a return to private industries like Ocean Farming Inc. For investing in the research there would, of course, have to be strong contractual provisions to assure the investors a return from their investment. The contract would also have to ensure that the fishery would not be decimated so as to negate the return from the fertilization effort. That would not be a problem under full privatization.

The return to the United States and the world from the success of such a program, leading to farming in the three quarters of the world covered by the oceans, could be great indeed. The benefits to America's economy would be more jobs and less costly food. But this bounty can only be reaped if private property rights, the necessary condition for maximum output from farms on dry land, are applied to the oceans as well.

Selected Readings:

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