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Achieving policy objectives to increase the value of the seafood industry in the United States: the technical feasibility and associated constraints

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Abstract

The paper first conceptualizes a program to triple the current value of aquaculture in the United States by 2025 to achieve production-driven policy objectives set by the Department of Commerce for the national industry. The program quantifies arbitrary targets for fish and shellfish, and outlines technical approaches. It discusses its spatial impact on the marine environment, concluding it is small compared with the number and magnitude of Marine Sanctuaries and Marine Protected Areas in federal and state waters. It discusses the magnitude of the task, concluding it is challenging but technologically feasible given an immediate start. Secondly, the paper identifies and explains many non-technical constraints. These include increasing per capita consumption of seafood, marketing seafood products, security of tenure and legislation, the availability of capital for investment, the need for aquafeeds, and changing economic and social attitudes. Each includes a description of efforts by the public and private sectors to overcome them, and where appropriate offers some solutions and directions for research.
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Keywords: Aquaculture; National policy; Seafood production; Offshore development; Spatial dimensions; Capital investment; Offshore technology; Constraints; Public attitudes

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Policy background

One element of the current aquaculture policy of the United States Department of Commerce (DOC) is to increase the value of domestic production from $900 million to $5 billion by the year 2025 (DOC, 1999) to help offset the $7 billion annual deficit in seafood trade. Several global and national trends provide DOC with rationale for optimism. The domestic industry has grown steadily over the last 25 years. Its value, in terms of edible fish and shellfish products at harvest, is just below $1 billion (DOC, 2003) and production approaches 500,000 metric tons (mt) live weight [1] (FAO, 2003a). It is acknowledged as the fastest-growing global food industry, and a major source of fresh, high-value commodities. These appeal to US consumers with their demand for quality and high-end finished products, and who spent an estimated $55.1 billion for edible fishery products in 2002, of which >69% was in seafood establishments and >29% in retail sales for home consumption (DOC, 2003). In the same year, seafood imports reached a record $10.1 billion, of which 40–50% was estimated to be farmed products from developing countries, and annual per capita consumption [2] jumped >5% to 7.075 kg, reaching its highest level since 1987.

But other trends are less optimistic. Gross domestic farm production for the last five years has remained essentially static between 430,000 and 480,000 mt live weight, and this has dropped the United States from 5th to 12th in global ranking (FAO, 2003a) as others countries have surpassed it. Detailed analyses of Department of Agriculture data (Harvey, 2003a,b) reveal that annual increases in fish in both fresh and saltwater have been offset by continuing declines in production of shellfish (both mollusks and crustaceans). The fledgling marine shrimp industry struggled under competition of producers in Latin America and Asia, and crayfish production fell after a series of hot dry summers. But the most serious problem has been the decline in the traditional mollusk industries, for reasons mostly beyond the industry's control. Important coastal fisheries for oysters and clams, and more recently with mussels, have been lost through all the consequences of population growth and coastal migration patterns, together with tightening regulations regarding local environment and food safety. These man-made constraints run directly counter to the man-made policies for 'sustainability' of these national resources.

Nonetheless DOC is optimistic that its production-driven policy goal by 2025 can be achieved, and in addition will benefit employment with 600,000 jobs and increase the value of exported goods and services to $2.5 billion. Dicks et al. (1996) estimated the national industry employed about 180,000 persons in 1996, and exported about $500 million in goods and services.

[1] The United Nations Food and Agriculture Organization (FAO) reports all global fisheries and aquaculture production statistics in whole live weights. The United States statistics differ in that they report mollusk production in the weights of their edible meats.

[2] The United States calculates consumption of seafood products per capita in terms of edible meat consumed (DOC, 2003). FAO calculates global and national consumption per capita based on the live weights of fish and shellfish available for human food (FAO, 2003b).

The technical feasibility of achieving policy objectives

A hypothetical program for national growth (2000–2025)

The DOC policy which targets the value of domestic aquaculture products to be $5 billion by 2025 contains no qualifications or quantifications specifying exactly what is to be increased, or by how much, or where. Consequently, this paper first conceptualizes a national development program to meet this financial challenge technically.

The hypothetical program assumes the target is:

- In 2025 money, which in real terms approximates to ~$2.5 billion, allowing for compounded annual growth rates and inflation.
- The value of edible seafood commodities only, and excludes increases in commercial value of cultured animals and plants for non-food commodities, such as medicines and drugs, research animals, jewelry and leather products, and craft materials.
- The value of edible commodities raised only by the systems and practices of aquatic farming, and excludes increases in value of culture-based capture fisheries or recreational fisheries through enhancement.
- Exclusive of any increased value of domestic landings of commercial and recreational fisheries. These have remained fairly static since 1993 (DOC, 2003), with declines in traditional fisheries being offset to some degree by the harvest of new species and improved use of by-catch.

Based on these assumptions, the program equates the financial objective to a tripling of the current annual domestic production by 2025. As production now stands more or less at 500,000 mt live-weight equivalent (FAO, 2003a), the program outlines new production of about 1 million mt of a range of species groups, the totals of which are 760,000 mt of fish, 47,000 mt of crustaceans, and 245,000 mt of mollusks. The contributions of each sub-group are detailed in Table 1.

The individual targets are arbitrary, but the numbers are rationalized on their proportionate disposition within the sector in terms of current production and value, and some recent trends. For example, the percentage ratio of fish to shellfish (73:27) accurately reflects a slow but steady change away from the historic ratio of 70:30, first reported by FAO in 1976, and more towards 80:20 as volumes of larger and heavier fish species come on line. The numbers are also realistic in terms of current technical achievements. These are described briefly for each sub-group by order of priority in the following sections, and quantified details of production systems and practices, with typical harvest yields and expected operational production per hectare (ha) at harvest, are given in Table 2.

Mollusk production

The program target projected for mollusk production is about 245,000 mt whole live weight. This is eminently possible as throughout the 1980s national production,

Table 1
Hypothetical aquaculture production program (in metric tons)

Group	Sub-group	Current US production	Program increase	Target for 2025
Mollusks	All	~100,000	245,000	345,000
	American oyster	40,000	10,000	50,000
	Pacific oyster	35,000	60,000	95,000
	European oyster	<1000	5000	5000
	Mussels	<2000	80,000	80,000
	Clams	25,000	80,000	105,000
	Scallops	<1000	5,000	5000
	Abalones	<1000	5000	5000
Crustaceans	All	~18,000	47,000	65,000
	Crayfish	14,000	35,000	49,000
	Freshwater prawn	<1000	3000	3000
	Marine shrimp	4000	9000	13,000
Fish	All	~340,000	760,000	1,100,000
	Anadromous fish	25,000	100,000	125,000
	Freshwater fish	~315,000	70,000	385,000
	Saltwater fish	<1000	590,000	590,000
Totals ($\sum$)		~458,000	1,052,000	1,510,000

mostly oysters, was invariably above 130,000 mt. There are no technical bottlenecks with any of the molluskan species already being produced domestically. As most require little or no daily management, they have significant potential for production offshore where space is more available. With political will the target for mollusk production could probably be achieved as early as 2015.

The first priority of the program is to rejuvenate the traditional oyster industry to its last historical highpoint of 150,000 mt, which was achieved in 1975. Current production is now only 40,000 mt of American cupped oyster, 35,000 mt of Pacific cupped oyster, and some European oysters. The rapid decline has been due predominantly to increased pollution in the aquatic environments and increased competition for coastal space.

The American oyster is mostly produced on sub-tidal lands. These are either state-owned, tribal-owned, or private sites which have the required environmental quality for extensive planting programs. Off-bottom culture with the species has not been successful. As it is unlikely that traditional lands can be recovered and/or reclassified as safe, then a more realistic goal is to make certain that all existing beds are protected and improved to enable the further production of 10,000 mt of American cupped oysters each year. The balance of 65,000 mt therefore rests with increasing production of the Pacific oyster and European oyster. Both these species are produced off-bottom on racks and stakes, or on ropes suspended from floating rafts.

The second priority is to expand the mussel industry from almost zero (about 2000 mt) to 80,000 mt. Mussels are the easiest and least costly of all shellfish crops to grow, and annual yields in productive coastal waters are extraordinarily high.

Table 2
Production practices for the program groups and estimated operational production at harvest[a]

Group/sub-group	Production practice	Unit dimensions	Average harvest yield	Operat. Prod. at harvest (mt/ha)
Mollusks				
American oyster	Sub-tidal land		1–1.5 kg/m^2	10–15
Pacific oyster	Raft/off-bottom	530 m^2, with 9 m ropes	3 kg/m^3	30 [b]
European oyster	Raft/off-bottom	530 m^2, with 9 m ropes	3 kg/m^3	30 [b]
Mussels	Raft	530 m^2, with 9 m ropes	10 kg/m^3	100 [b]
Mussels	Headline and rope		20 kg/m	40 [b]
Clams	Sub-tidal wild set		1 kg/m^2	10
Clams	Sub-tidal seeding		5 kg/m^2	50
Scallops	Sub-tidal enclosure		2 kg/m^2	20 [b]
Scallops	Headline and lantern net	8-tray net, 2–3 m vertical	3–3.5 kg/m^2	4 [b]
Abalones	Shore-based tank	25 m^2, 1–1.5 m deep	1–1.5 kg/m^2	100 [b]
Crustaceans				
Crayfish	Managed pond	2–4 ha pond, 2 m deep	0.1 kg/m^2	1
Freshwater prawn	Managed pond	0.5–1 ha pond, 1.5–2 m deep	0.1 kg/m^2	1
Marine shrimp	Shore-based raceway	400–1500 m^2, 1–1.5 m deep	5 kg/m^2	20–50 [b]
Fish				
Anadromous fish	Net–pen complex	4800 m^2, 10 m deep	30–60 kg/m^3	432–864 [b]
Freshwater fish	Semi-intensive pond	0.5–1 ha pond, 1.5–2 m deep	0.3 kg/m^2	3
Freshwater fish	Raceway, or round tank	25×2.5 m, or 5–20 m diam., 1 m deep	7.5 kg/m^2	75 [b]
Saltwater fish	Net–pen complex	4800 m^2, 7–10 m deep	10–30 kg/m^3	144–432 [b]
Saltwater fish	Small offshore cage	3000 m^3 submersible/conical	30 kg/m^3	27 [b]
Saltwater fish	Large offshore cage	22,000 m^3 submersible/conical	30 kg/m^3	99 [b]

[a] Harvest is projected in the second year, although some species can be harvested within their first year.
[b] Denotes operational production area includes space for access and movement of vehicles, boats, feed barges, and any life-support systems, but not space for hatchery buildings, office buildings, laboratories, maintenance shops, storage, piers, etc.

Mussels grow prolifically on ropes suspended from floating rafts or from head-ropes strung between anchored floats, or by the traditional method of poles or stakes pushed into the substrate.

The third priority is to expand the interest in a range of mollusks which are being produced in the United States and other parts of the world. These include clams, scallops, and abalones. In the last 15 years these relatively new industries have indicated their potential for growth. Clam culture is the most productive, with about 25,000 mt of hard clams produced annually through enhancement and another 1000 mt of other clam species. A practical target for an increase in clam production is about 80,000 mt, using new submerged and tidal lands.

Together, annual production of scallop and abalone is probably less than 10 mt. Modern methods for the production of scallops include lantern nets suspended from floats or ropes, and by bottom-culture in pens protected from predators. Abalones are raised in small shore-based tanks, using pumped seawater. The global industries of both sub-groups are improving rapidly, and increasing production to 5000 mt annually is a very attainable target for each one.

Crustacean production

The program target projected for crustacean production is 47,000 mt whole live weight. This will be difficult to achieve, as production costs for all crustaceans in the United States remains high compared with those in Asia and South America, mostly because of cheaper labor or the technology being used. National production of crustaceans will always be modest at best.

The first priority is to revitalize freshwater crustacean production. A feasible target for red swamp crayfish is an increase of 35,000 mt from its present depressed level. This would take it beyond the historic high point of 44,000 mt reached in 1986. Although annual production frequently averages 20,000–30,000 mt in wet years, the market remains predominantly local and the industry lacks processing capacity to expand nationally. Production of freshwater prawn has almost disappeared after a promising start in the 1980s, therefore a new goal of 3000 mt is conservative. Both goals for these two species are readily achievable with little added investment as there are about 50,000–60,000 ha of earthen ponds currently in some form of use, and these can be upgraded.

The second priority is to increase marine crustacean production by 9000 mt. Marine shrimp production remains small overall, but has risen in recent years to about 4000 mt with intensive production in raceways with total life-support systems. These high-technology practices are now the best option for achieving this modest production figure, as developing coastal lands for ponds of any sort is prohibited in almost every state.

Fish production

The program target projected for cultured fish production is about 760,000 mt whole live weight. Because of the need for more technology before production of many marine fish species is practical, the target could be divided into a short-term goal (by 2015) for freshwater and anadromous fish, and a long-term goal (by 2025) for marine fish.

Investment activities in the short term would focus on production practices which again avoid technical bottlenecks. Therefore, the first priority is to expand the production of anadromous fish, such as Atlantic salmon and rainbow trout, by 100,000 mt using salt-water net-pens. Current production of these fish in saltwater in the country is about 25,000 mt, but the domestic market consumes another 100,000 mt imported from Canada, Chile, and Norway (Harvey, 2003a). There are no technical difficulties in producing salmonids in saltwater, and therefore it is feasible in the short-term to recapture the lost market share with domestic products.

The second priority is to expand annual production of the currently popular freshwater fish raised in ponds and tank farms by 70,000 mt. Current production of the most common fish include catfish (about 271,000 mt), rainbow trout (26,000 mt), hybrid striped bass (5000 mt), tilapia (8000 mt), edible carps (3000 mt), and others (<2000 mt). As the domestic market consumes another live-weight equivalent of 15,000 mt of tilapia, imported mostly from Taiwan, China, Ecuador, and Costa Rica, and 9000 mt of imported Asian catfish, it is feasible in the short-term to consider increasing domestic freshwater fish production in both ponds and raceways, probably without much expansion in capital facilities as many farms are now operating under capacity and ponds lie fallow because of low market prices. Harvey (2003b) reported catfish growers had over 5% less ponds in production in 2003 than 2002, and expected to have only 71,000 ha in use in the last six months of 2003. Huner (2003) estimated there are about 100,000 ha of inland ponds devoted to warmwater fish production in the country. The program could divide the target between different production systems, say 60,000 mt in intensive production tank farms, and 10,000 mt of warmwater fish in well-managed earthen ponds, with perhaps some polyculture.

The third priority is for production of marine species, preferably those already in demand on seafood markets and/or with production technologies already advanced. Unfortunately few marine species are being produced in quantity at the present time, as technical problems still remain. Intensive production of 590,000 mt of marine fish will mostly require sturdy structures in the form of submersible sea-cages engineered for locations offshore.

The program cost

Capital investment in saltwater fish production

Saltwater fishes, both anadromous and true marine fish, may be propagated artificially in hatcheries or harvested as wild juveniles, and grown out in highly-engineered marine structures. The cost of a 12-unit net–pen complex suitable for more protected coastal areas is $800,000–1,300,000, depending on the anchorage requirements. For offshore exposed waters, the cost of the current array of submersible cages is about $30–35/m^3 installed on site. A modern feed barge, complete with a range of facilities to service a number of units and personnel, is about $300,000.

The alternative to coastal and offshore development is production in land-based saltwater recirculation units. In a recent study for the Danish government (Anon, 2003), the investment cost for on-growing Atlantic cod on shore, but excluding capital cost and land purchase, was estimated to be $12.5 million per 1000 mt of production.

Capital investment in marine mollusk production

Investment in marine mollusk production will be far less than that for saltwater fish, but still significant because of the diversity of technologies and spatial requirements. For production of mussels, Pacific oysters, and European oysters the cost of a long-lasting aluminum raft and its anchorage is in the order of $50–60/m^2, and one made of wood and galvanized steel about $25–30/m^2. For mussels grown on polysteel rope suspended between floats, the cost of rope (12 mm diameter), together with socking fabric and floats in place but excluding anchorages, is between $400 and 450/km.

The American oyster and clams require the use of sub-tidal areas. The annual fee for leasing submerged lands for shellfish production varies from state to state. Typical fees range from $4 to 25/ha (Marsh et al., 2002), but in states where areas are limited, fees can range from $75 to 500/ha.

For scallops raised intensively in lantern nets, the cost of an individual net with trays, excluding all flotation and attachments, ranges from $6 to 10, according to the size of mesh. Abalone are raised in small shore-based tanks supplied with seawater. However, the cost of low-bank coastal land in the United States, when it is available for development, is always high ($200,000–300,000/ha), as is the energy cost of pumping.

Capital investment in crustacean production

Freshwater crustaceans are raised semi-intensively in well-managed freshwater ponds. Freshwater prawns do better in 1 ha ponds, and red swamp crayfish in larger 1–4 ha ponds. A typical cost for construction of a crawfish pond is $2000–2500/ha, and $6000–10,000/ha for a prawn pond as the berms must be higher and well compacted. Crayfish are also raised extensively in some of the thousands of hectares of suitable rice lands available throughout the southern states.

Capital investment for marine crustaceans production is high. The cost of a raceway unit, and all its life support and site support systems, is in the range of $110/m^2. Compensation for this high cost is the fact that the total number of units required for a commercial operation is small.

Capital investment in freshwater fish production

The smallest capital investment program is required for raising the traditional freshwater pond fish, such as catfish and edible carps in polyculture, as the necessary area of ponds is probably already available. The average construction cost of a new warmwater fish pond is about $8000–12,000/ha.

Intensive production in tank farms and raceways for fish such as trout, hybrid striped bass, tilapias, and sturgeons, etc., is dependent primarily on the water flow rate and the species concerned, and costs are difficult to generalize. However, excluding any land costs and hatchery, capital costs for the construction of a typical tank farm with water delivery and treatment system are in the order of $400,000–500,000/ha.

The dimension of space

Estimates for the spatial requirements of the target production for each of the groups and sub-groups are given in Table 3. They are based on the data derived in Table 2 for production per hectare at harvest in the second year. The requirements include space for the necessary operational activities around each production facility but exclude space for first-year nursery production, hatcheries, support buildings, and other land-based services. An estimate of nursery space as a percentage of grow-out space is added for each sub-group, although this may not be required in the same environment or for the same length of time. Some nursery spaces for marine fish would be on land, and grow-out to harvest might take only one year or less.

In summary, the total spatial demands for the different components of the proposed aquaculture development program to produce an additional ~1 million mt of seafood for human consumption by 2025 are relatively small. The program conceptualized to meet the national goal, and selecting the total production option which demands the maximum space, requires an area equivalent to less than 1000 km^2. This is divided equally between inland freshwater space (52%) and saltwater space (48%), some of which (15%) is also on land. Combinations of different practices to meet the goal, such as using both small and large offshore cages for marine fish, might reduce the area by 10–20%.

Envisaging a square kilometer of surface waters is difficult at best, and therefore 1000 km^2 may appear large superficially. But in reality this total is very modest when compared with the scale of agriculture in the United States; for example, over 310,000 km^2 of corn are planted annually (NASS, 2000). The individual areas are also quite modest when compared with some tangible national features; for example, 80,000 mt of mussel production on ropes requires an area less than the Kennedy Space Center at Cape Canaveral (about 25 km^2), and 100,000 mt of anadromous fish in net-pens requires an area about the size of the Pentagon (2.36 km^2).

More significantly, the maximum requirement for all program activities in coastal and offshore marine waters is in the order of 400–500 km^2. By comparison, the 13 National Marine Sanctuaries around the United States range in size from 1–13,725 km^2 and occupy a total of 48,220 km^2; and the largest of 104 Marine Protected Areas in California is already 453 km^2 with plans to extend it to 1103 km^2.

Calculating the potential scale of various aquaculture production activities, and comparing them with those of agriculture or even some national landmarks, provides a perspective which is interesting but not practically relevant. Although zones

Table 3
Total (∑) spatial requirements (in km^2) estimated for the program targets

Group/sub-group	Production options	Program target (mt)	Grow-out requirements (mt/ha)	∑ Grow-out requirements (km^2)	Plus nursery space[a] (% ∑Grow-out)	∑ Spatial requirements (km^2)
Mollusks		245,000		<150		Max. ∑ < 175
American oyster	Sub-tidal land	10,000	10–15	6–10	20	7.2–12
Pacific oyster	Raft/off-bottom	60,000	30	20[b]	20	24
European oyster	Raft/off-bottom	5000	30	2[b]	20	2.4
Mussels	Raft	80,000	100	8[b]	10	8.8
Mussels	Rope	80,000	40	20[b]	10	22
Clams	Sub-tidal wild set	80,000	10	80	20	96
Clams	Sub-tidal seeding	80,000	50	16	10	17.6
Scallops	Sub-tidal enclosure	5000	20	<3[b]	20	3.6
Scallops	Lantern net	5000	4	<13[b]	25	16.25
Abalones	Shore-based tank	5000	100	0.5[b]	100	1
Crustaceans		47,000		385		Max. ∑ < 427
Crayfish	Managed pond	35,000	1	350	10	385
Freshwater prawn	Managed pond	3000	1	30	20	36
Marine shrimp	Shore-based raceway	9000	20–50	2–5[b]	10	2.2–5.5
Fish		760,000		<266		Max. ∑ < 297
Anadromous fish	Net–pen	100,000	432–864	1–2.5[b]	10	1.1–2.75
Freshwater fish	Semi-intensive pond	10,000	3	<35	20	42
Freshwater fish	Raceway, or round tank	60,000	75	8[b]	20	9.6
Saltwater fish	Net–pen	590,000	144–432	14–41[b]	10	15.4–45.1
Saltwater fish	Small offshore cage	590,000	27	<220[b]	10	242
Saltwater fish	Large offshore cage	590,000	99	60[b]	10	66
All groups		1,052,000		<801		Program ∑ < 899

[a] An allowance is made for nursery space, although some may be unnecessary or on-shore.

[b] Denotes requirement includes space for access and movement of vehicles, boats, feed barges, and any life-support systems, but not space for nursery operations, hatchery buildings, office buildings, laboratories, maintenance shops, storage, piers, etc.

measured in square kilometers may be set aside for offshore aquaculture, they will be relatively small in area, and not densely packed. Development policy and regulations will discourage intensive localized production for a variety of economic, social, and environmental reasons, and production will be dispersed sensibly along the United States coastline and in the Exclusive Economic Zone (EEZ). Furthermore, while the United States may have more than 154,000 km of coastline and an EEZ of about 9 million km^2, even without the competition from other resource users these potential expanses of coastline and marine waters are by no means all suitable for marine aquaculture. For example, in all probability it will be impractical to work in offshore state or federal waters at depths greater than 200 m; and some locations will be just too remote from suitable terrestrial space which, because offshore aquaculture is mostly a grow-out operation, will provide logistical support in the form of hatcheries and general farm services, as well as nursery facilities for raising juveniles until ready to go into grow-out facilities. Other areas may have low productivity and will not sustain economic production of certain types of aquaculture, and some may be just too inhospitable. Furthermore, certain areas offshore are already identified for other uses, such as national sanctuaries, marine reserves (harvest refugia), dumping grounds, and military maneuvers. However, despite all these reasons for reducing the space theoretically available for a marine aquaculture program, the spatial impact of offshore aquaculture, as illustrated in Table 3, will in sum be much less than 1% of the area of the National Marine Sanctuary Program administered by the National Oceanic and Atmospheric Administration (NOAA), and more similar in size to one of the many Marine Protected Areas now being created in state and federal waters.

The practical magnitude of the task

With a balanced program of development, it is feasible to produce the additional ~1 million mt of aquaculture products by the year 2025, but much will depend on meeting the technical challenges of rearing and feeding the marine fish species which can yield the gross weights necessary to achieve the goal. Based on historic growth of the catfish industry in the United States, and the Atlantic salmon industry in Norway, Chile, and Scotland, it takes 10–15 years to build an industry above 50,000 mt, once the technology is more or less in place. This time constraint is due predominantly to the life-cycle characteristics of each; for example, it may take 1–2 years for non-tropical species to attain marketable size but possibly 2–5 years to become sexually mature.

A number of marine species are now being produced successfully after first breeding and propagating in land-based hatcheries. The list includes economically valuable species such as cod, cobia, moi, drum, snook, pompano, and a number of flatfishes, such as flounder, halibut, and sole. Several others are being grown out on farms after first being harvested as wild juveniles. These include some tunas, horse mackerels, and amberjacks. From such a list of 12–15 species of indigenous marine fish now being raised in captivity, it requires at least six within the next 20 years to fulfill farm potential of between 50,000 and 100,000 mt, and another six to fulfill farm potential of between 25,000 and 50,000 mt, to achieve the goal of 590,000 mt.

The potential for production of this significant volume by weight of marine fish is considerable but real. Norway, for example, which is just now beginning to bring quantities of Atlantic cod to the market, is building hatcheries and predicting production of about 200,000 mt by 2010, and 400,000 mt by 2015 (Anon, 2003). Cobia has suddenly appeared as a useful farm fish, and Taiwan already reports production of 1500 mt. For many years, Japan has fattened over 150,000 mt of amberjacks and horse mackerels in sea-cages, and this technology is now being applied in several countries where fishermen are taking their quotas of southern bluefin tuna as younger fish for fattening because of their extraordinary value as adults.

Shellfish farming can be equally productive, as demonstrated by the number of countries which have achieved some significantly high production numbers in a short period of time. In Japan, for example, in 1970 the scallop fishery in Hokkaido was totally depleted. Through hatchery production and seeding out, production is now over 200,000 mt (FAO, 2003a). Similarly, China had no record of scallop production in 1976, but now raises four species which currently yield over 1 million mt live weight, annually (Jia and Chen, 2001). Therefore an annual target of 240,000–250,000 mt of mollusk production in the United States by 2025 is quite conservative. Nonetheless, the magnitude of the entire production program still remains considerable, and is very much dependent on an immediate start.

Non-technical constraints to achieving policy objectives, and possible solutions

Achieving production-driven policy objectives may be feasible in the long-term with conventional technology advanced by successful on-going research, but there are many associated non-technical constraints which need to be overcome. This part of the paper describes these constraints and some current approaches to resolve them.

Increasing per capita consumption of seafood

Any national policy to increase the value or volume of any domestic food commodity cannot succeed without the driving force of the market, in this case American consumers. Although the United States is one of the prime global markets for seafood, evident by its enormous imbalance in trade, its citizens are not large eaters of fish. In 2003, the annual per capita consumption of seafood at the retail level was a modest 7.1 kg compared with 98.6 kg for red meat and poultry (Southard, 2003).

In order to absorb the addition of over 1 million mt whole live weight of farm products by 2025, the average consumption of fish and shellfish by the present population of 282 million must increase. In terms of whole live weights, the annual per capita consumption of seafood in the United States is 21.2 kg (FAO, 2003b). The

World Bank (2003) projects annual population growth to decline to 0.8% between 2001 and 2015, and forecasts a population of 318 million. If this total remains static between 2015 and 2025, which is probable as annual growth of most western countries is forecast to be zero or even negative by 2015, then consumption of fish and shellfish must increase by only 3.14 kg per capita live weight equivalent to absorb the increase.

Raising consumption to 24.75 kg per capita live-weight equivalent is certainly within reach, as the figure is low compared with countries of Southeast Asia and Scandinavia, and similar to many western European countries. Conditions are favorable, as some positive trends are already taking place. For example, aquaculture products, such as marine shrimp, catfish, and salmon, are now well-established in US markets. Their diversity makes them competitive with traditional forms of red meats and poultry, and they can be obtained throughout the year. They are typically available fresh, not frozen, and the global market consumes about 52.3% of all edible fish and shellfish harvested as fresh products (DOC, 2003).

Surveys show that seafood products are popular with consumers, who are continuously increasing their annual expenditures on eating outside the home as well as increasing retail purchases (DOC, 2003). Both trends are aided by the burgeoning growth in the number of elderly persons, as the 'baby-boomers' of the 1950s and 1960s are now reaching the age of retirement and appear to have a distinct preference for seafood for health reasons. Seafood products are also readily processed into convenience foods. This new market is timely, as traditional seafood retailers have almost disappeared and super-market outlets realize they are unsuited to the task of handling fresh product and can make more profitable use of floor-space. Hence retailers now prefer to sell seafood in portions, pre-prepared and packaged for everyone's convenience.

Despite these positive signs there is no evidence that the US consumer might prefer to buy domestic products, given the choice. Seafood imports are at an historic high level, and ironically 40–50% are estimated to be farmed products. Therefore, the long-term outlook for the US producer continues to be head-to-head competition with overseas producers. Foreign competition, particularly from developing countries, will continue to offer similar and low-priced commodities in the marketplace. This is because these nations have their own goals to increase aquaculture production in coming years, and they have justified loans from international development banks on the voracious and lucrative seafood markets in the United States, Japan, and the European Union. They have planned to repay their loans through the sale of high-value products made profitable by low labor costs of production, and more importantly of processing. Provided that their aquaculture products meet the higher standards of human health and safety, now imposed by the western world on all food products, seafood producers in the United States will always face competition for market share.

The solution for the domestic producer is to offer a range of products which are affordable, and preferably have some regional connotation or niche which makes them recognizable as home grown. This strategy places high priority for economic-related research; for example, selection and concentration on species highly suited to farm conditions, selection of species which have a high fillet yield, and the mechanization of farming operations.

Marketing seafood products

It appears opportune for the US market to increase its capacity for seafood, but this will not happen on its own. A significant and prolonged marketing effort by all seafood producers, processors, and retailers, and supported by state and federal policies and services, is going to be required. Regrettably, there has been a growing polarization between fishermen and farmers which, through agitation by the media, surfaces at retailers in the form of negative product comparisons.

Commercial harvesters raise many issues about fish and shellfish farming as they see products competing in the marketplace threatening their livelihoods, and they have found temporary friends in non-government organizations pursuing their own agendas against aquaculture (Chatterton, 2004). While it is true that domestic landing prices have dropped as processors and retailers find new suppliers, competing products are for the most part high-value imports and not domestic products. Within the annual supply of 4.3 million mt of edible products, there is in fact little head-to-head competition between US fishermen and US farmers in markets for the same or similar species, with exception of farmed Atlantic salmon and hatchery-reared Pacific chinook salmon caught commercially.

Rivalry within the domestic seafood industry is not in the national interest. Its reunification, combined with the goal of increasing per capita seafood consumption, requires some new vision and commitment by federal and state governments. Putting the organization and management of capture fisheries and marine aquaculture on an equal footing within federal and state agencies, for example, and recognizing their commonalities as well as their differences, would be a start. But in the long-term, their symbiosis would be best resolved through a common seafood authority, such as the National Fisheries Institute or National Seafood Producers Council, with responsibility to promote generic seafood for the benefit of all producers. However, government funding will have to be a necessary part of such a program, supplementing contributions from the many industry sub-sectors which want to be assessed equitably.

One difficulty with any generic marketing program is to persuade the consumer to give preference to domestic products. The United States goes to great lengths to promote free and fair global trade, but fulfilling this policy is not without its anomalies, and competing with overseas producers has been helped to a degree by certain legal twists and turns of policy-makers. These include, for example, requiring country-of-origin labeling, labeling catfish from Asia as ‘basa’ instead of catfish, identifying farmed products, imposing high standards for residual veterinary medicines, the use of color additives, stringent monitoring of processing practices overseas, and spot-checks of imported products. There are also occasional allegations by the DOC of dumping, such as boneless salmon fillets from Chile, and shrimp from Viet Nam and China, and proposals for punitive tariffs.

The approach to bias a marketing policy in favor of domestic products is again a healthy and safe quality product which the consumer can afford, without jeopardizing its high-value seafood image, and one which can be identified and promoted by food service industries. In addition to fine-tuned production costs, this means that monitoring health and safety does not come with a plethora of regulations and checks which increase the financial burden. But quality control is important, as seafood can deteriorate quickly and become unsanitary, and many shipments have been refused entry for just this reason. Therefore research priorities must be on developing quick and accurate tests, accepted and adopted internationally, for the suite of residues and toxins which might be present in seafood products.

Security of tenure, and legislation

The institution of property rights in the United States has been responsible for its economic and social development, providing security of tenure for a myriad of business and personal enterprises to borrow capital. Even the air-waves have been profitably assigned and regulated by the Federal Communications Commission since 1934, and the goal of the Telecommunications Act of 1996 is to let anyone enter any communications business, and compete in any market against one another. Unfortunately the policy has not been applied yet to sea-waves, and aquaculture development remains constrained by failure of successive governments to assign rights to areas of the seabed and its water column, and rights to possess and classify aquatic animals and plants under culture as domestic and not wild.

Legislation to provide security of tenure was identified as the solution to encourage national investment and development of aquaculture almost 30 years ago. The National Aquaculture Act of 1980, and the National Aquaculture Development Plan of 1983 produced by the Joint Subcommittee on Aquaculture recommended improvements to federal legal and administrative frameworks to permit and regulate commercial enterprises in public waters, including federal marine waters. Ten years later, the National Research Council (NRC, 1992) noted that the issue remained unresolved, and recommended federal and state governments to structure the regulatory and funding frameworks needed to encourage growth while also addressing environmental concerns.

One reason for the lack of progress is the separation of federal and state waters, and then differences between state waters. The federal government is responsible for waters beyond the limit of states' jurisdictions to 200 nautical miles (the EEZ), but it has no legal or administrative process for leasing areas for the conduct of private aquaculture. The 28 coastal states and five island territories are responsible for coastal waters, as clearly mandated by the Coastal Zone Management Act of 1972. Consequently there is a plethora of state laws and regulations applicable to aquaculture, few of which are uniform, and complex administrative processes for different licenses, permits, and certificates. Furthermore, the states and even their counties frequently interpret federal and state laws differently. These anomalies and complexities in the legal and regulatory processes have been so discouraging to investment that many prospective entrepreneurs have located overseas, where administration has been simple, efficient, and equally protective of the environment.

In April 2004, the preliminary report of the US Commission on Ocean Policy (COP, 2004) acknowledged the growing significance of marine aquaculture and made a number of recommendations for its future sustainability. It pointed out once again that the country needed a coordinated and consistent policy, regulatory, and management framework for marine aquaculture, which should be implemented by federal and state agencies with full participation by industry. The Commission recommended NOAA to be the lead federal agency, with a new Office responsible for organizing and managing a comprehensive, environmentally-sound permitting, leasing, and regulatory program.

NOAA has already been moving in this direction on its own volition. As several of its line offices have specific responsibilities which inter-act with aquaculture, or conduct relevant research, the agency in 2003 elevated aquaculture as a matrix program. In addition, NOAA Fisheries (NMFS) has been working on issues raised by stakeholders to enable aquaculture development in the EEZ. As the United States was a signatory to the FAO Code of Conduct for Responsible Fisheries in 1995, the agency drafted a Code of Conduct for Responsible Aquaculture in the United States EEZ, which was published in 2003. NMFS has also drafted the basic language of a proposed National Offshore Aquaculture Act, which has been revised subsequently by all NOAA line agencies to reflect their specific mandates with regard to marine resources. The proposed Act should be presented to the US Congress during the current session. Consequently, these actions fulfill many of the recommendations by the US Commission on Ocean Policy for development of sustainable marine aquaculture, including the funding for research, development, training, extension, and technology transfer.

The proposed Act and the Code are therefore important steps to enable the government's policy objectives to be achieved. Together, they provide security of tenure for producers without jeopardizing the security of the offshore environment. However, there is still the process of rulemaking, and if producing affordable seafood is the key to a successful domestic aquaculture industry, then the need is a streamlined and responsive process which does not impose burdens of delay and unnecessary cost which have plagued permit applications in the past.

The availability of capital

Given new legislative and administrative frameworks for the aquaculture sector, achieving production targets for its various commodities by 2025 will depend on considerable financial investment in the engineering and construction of containment structures, together with their installation, operation, maintenance, and insurance – particularly in marine waters. Consequently, the lack of both fixed and working capital to implement a production program is yet another impediment to its success.

The United States has provided little or no financial support for development of the aquaculture industry, with the exception of research funds. By comparison, between 1989 and the end of 1999, the European Union ploughed ECU 16 thousand million of structural funds into 'zones dependent on fisheries and marine fish culture'. These were distributed among 13 countries, of which Greece (4.5 thousand million), Portugal (2.8) and Spain (2.6) took the lion's share. Member countries also took advantage of schemes specifically designed for fisheries and aquaculture (such as fishing vessels, aquaculture farms, hatcheries, harbors, processing plants, etc.), and non-specific schemes, such as general industrial and social development funds to help regions lagging behind EU norms. With this extraordinary amount of financial help, the 13 countries of the European Union have doubled their production of fish and shellfish from about 620,000 mt to some 1,200,000 mt.

Various US government departments and their agencies offer a range of specific schemes for the development of commercial sectors, particularly the Small-Business Administration. NMFS provides long-term debt financing through its Fisheries Finance Program, which is self-supporting. These low-interest loans are primarily for constructing (or retiring) fishing vessels and coastal facilities, but since a recent amendment of its statutory authority aquaculture projects have become eligible. Unfortunately the annual loan ceiling approved by Congress has made the program too small to meet new demands. NMFS also manages the Capital Construction Fund, which is a tax incentive scheme, and the Saltonstall–Kennedy Program, which provides modest grants for research.

Although aquaculture enterprises are eligible to apply to these government-funded programs, in practice the high financial risk of marine aquaculture projects, many of which are pioneering, bring rejection or carry a penalty. Therefore policy changes are needed to adapt current finance schemes for the benefit of aquaculture enterprises, or to create a new venture capital revolving fund for passive equity investments in the most promising projects.

There are also opportunities for other government support services. For example, the Risk Management Agency in the Department of Agriculture is currently investigating the feasibility of aquatic livestock insurance schemes, similar to those provided for terrestrial livestock. However, private insurance schemes have been available to aquaculture farmers since the early 1980s.

The need for suitable aquafeeds

Achieving the government's policy objective will be constrained to some degree by the availability of suitable compounded aquafeeds. With the exception of certain mollusks, all farmed aquatic animal species require artificial feeds of some type. An annual production of 1 million mt of farm fish may require 1–5 million mt of compounded feed, depending on its formula and conversion rates. For omnivorous fishes, like catfish and tilapias, feeds contain proteins which are largely of plant origin. For carnivorous fishes, like most marine species, feeds contain proteins mostly of animal origin, particularly high quality fish meal and fish oil.

Protein ingredients in compounded feeds greatly influence their cost, and the cost of feed is invariably >50% of the annual production costs of farmed carnivorous fish.

As the availability of high-grade fish meal and fish oils fluctuate each year, global prices have ranged between $440 and $900/mt. Based on current formulations, the program target of 740,000 mt of saltwater fish would require about 74,000 mt of fish meal annually. This is a relatively modest demand on the available resources by the United States, but one which cannot be guaranteed in a future global context as other countries are already producing larger quantities of fish and projecting similar aquaculture growth.

The solution is clearly in research, and the need for suitable aquafeeds not dependent on limited and costly ingredients has been long-recognized by animal feed manufacturers, among others, and investments in feed technology have been considerable. In addition to the search for alternative sources of fish meal and fish oils, such as trash fish, by-catch, and processed offal (Nautilus, 2003), there is ongoing research to substitute these fish proteins with cheaper but suitable alternatives (Hemre, 2002). The likelihood of success is considerable, and therefore achievement of the program targets in 2025 should not be dependent on the future availability of fish meal and fish oils.

Changing economic and social attitudes

Future efforts to increase seafood production and consumption in the United States may be impeded by changing economic and social attitudes associated with some changing demographics. For example, more than half the population now lives in its coastal states. Yet growth differences within these states show preferences for non-coastal counties compared with coastal counties (Perry and Mackun, 2001). This is because livelihoods are no longer dependent on the traditional, labor-intensive coastal industries, such as mercantile marine, ship building and repair yards, mining, and even fishing. Coastal states are now home to more modern and urban individuals pursuing a lifestyle sustained by all the components which make up the environment, rather than its economic functions. Consequently, they are often inimical towards any interference with their agendas, and oppose most economic development. Although consumption of good food is invariably a part of their lifestyle formula, local production is not in the equation. As a result, farmers (both terrestrial and aquatic) and commercial fisherman are frequently their targets with deliberate misinformation about perceived impacts of their industries on water quality, ecological habitat, genetic diversity, and even the health and safety of their products (Chatterton, 2004).

But it is the coastal residents who have been putting more pressure on an un-prepared marine environment, with ensuing changes in land-cover and land-use directly intensifying pollution in most coastal waters and wetlands. Puget Sound in Washington State, for example, is now labeled a 'stressed' environment (PSWQAT, 2002), having doubled its population to 4 million since the 1960s. The traditional shellfish industry has been hardest hit by the disruption of hydrological systems, erosion, and degradation by urban contaminants from sprawling coastline development, and extensive tidal lands for harvesting have been reclassified and downgraded. Marsh et al. (2002) state that over 31% of the nation's shellfish growing waters, estimated to be 8.8 million ha in 1995, are now harvest-limited; others have been lost altogether, and long-standing leases are not being renewed as businesses become unprofitable. Coastal fisheries have also declined, as estuarine breeding grounds and nurseries are challenged by marinas and servicing centers for recreational boats which, according to Fedler (2000), increased across the country in the 1990s by 14%. Neither aquatic farming or commercial harvesting, both of which are susceptible to all types of pollution, cannot compete with such demands without some protection for locations where seafood for human consumption can be produced and harvested with safety.

The obduracy of coastal communities towards the seafood sector, and all that it entails, could be reversed by stronger leadership from the coastal states. Since the passing of the Coastal Zone Management Act of 1972, the coastal states and island territories have the authority to manage their own independent coastal programs for the common purpose of promoting stewardship on a variety of issues, and advancing national management objectives. Because of the diversity in the economic base of each state, the length of their access to the coast, and the variety in their ecosystems, the states and territories rate their priorities quite differently. Those reliant on tourism, for example, have different priorities to the more industrial states. So far, few states envisage the economic benefits of aquatic farming in their purview. Nelson et al. (1999) reported that only 10 of 17 states responding to their survey on coastal zone management plans had an aquaculture component; and only three states recognized marine aquaculture as a high priority in a separate assessment of the nine special enhancement areas prioritized for funding under the Act.

The aquaculture industry in the United States is very conscious of changing public attitudes, and is committed to doing the right thing. It believes it is a clean water-related industry by comparison with many others, and it is concerned for the welfare and humane treatment of its livestock. As all aquatic species depend on a good environment and minimum stress for their survival, it is not in the interest of producers to create detrimental conditions. To these ends, the majority of producers have affiliated to promote their respective interests for their collective benefit. They have formed organizations by a common product, such as the Pacific Coast Shellfish Growers Association, or by region, such as the Maryland Aquaculture Association. For their further protection, most of these organizations have prepared rigorous best management practices (BMPs) for their respective cultures, based on the best scientific information available at the time. When these guidelines are implicitly followed, risks to the environment are minimized.

BMPs are not compulsory, however, and transgressions are identified continually by regulators. Therefore one way to raise the level of importance of BMPs is to make them a key component of the permit process. Although producers may baulk at the loss of flexibility to deal with an atypical situation, this policy would benefit them by simplifying each permit, and reducing time and cost of process; for example, if a producers requests a permit to raise scallops in lantern nets in offshore waters, the conditions under which it may be done are immediately available without specific and protracted environmental study, and these are attached to the permit.

An integrated permit policy requires the preparation of BMPs for a range of production methodologies and a variety of species. Furthermore, BMPs must be prepared by producers and regulators working together. Again, this has advantages for producers. As BMPs are science-based documents, the policy will necessitate funding for research on identifiable areas of priority by both public and private sectors.

Compliance with science-based BMPs or the publication of scientific facts has not been sufficient so far to change public attitudes towards aquaculture or, for that matter, other natural-resource-based industries such as fishing. Resolving the problem is going to be long-term, and depends on a better understanding of community perception towards seafood producers. A series of case studies carried out in Australia on public attitudes towards natural resources management, including aquaculture (Majur, 2004), is producing valuable information on the needs of stakeholders and how they think, and it is only such social research which will provide guidelines for federal and state policy-makers to overcome this issue for seafood in the United States in the future.

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