Increasing public involvement in enriching our fish stocks through genetic enhancement

Harlyn O. Halvorson a,*, Fernando Quezada b

a Policy Center for Marine Biosciences and Technology, University of Massachusetts, Boston, 100 Morrissey Blvd., Boston, MA 02125, USA
b Biotechnology Center of Excellence Corporation, Nine Park Street, Boston, MA 02108, USA

Abstract

A total of 70% of the world’s conventional commercial fish species are now fully exploited, overexploited, depleted or recovering from depletion. This dramatic crash in the capture world fisheries production has led to problems in foods distribution, balance of payments, employment, and ecological depletion. Public support for breeding programs with terrestrial farm animals and plants in agriculture have revolutionized this industry over the past few hundred years. However, new genetic rearing technologies to improve marine animal production through aquaculture that utilize modern biology to obtain sustainable aquaculture and preserve biodiversity provide a promise to address these problems. However aquaculture has not been subject to public discussion and approval. Public involvement, not necessarily acquiescence, provide value added in the decision making process. Public understanding and involvement involves three stages. (i) Public concern over the pool of genetic information; (ii) if aquaculture is to respond to the fisheries crises with innovation, the knowledge gap between public understanding and scientific information must be bridged; and (iii) strategies must be developed for achieving this. Release of recombinant DNA to the environment, and handling exotic species, are useful case studies. Illustrations will be given of communication bridges to the public and ways to involve the public in making policy decisions. © 1999 Elsevier Science B.V. All rights reserved.

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1. Technology and public support

Technology is the engine which drives our modern society. For this process to work the public must be involved which provides value added to the process. When technical decisions require science a new gap of understanding is opened. We have to learn how to engage people concerned about human relations versus human resources, to make a significant contribution to the process. They need to have the technical details described in a balanced manner and in language which they can understand.

The history of advancing technology is no more evident than in the practice of agriculture. It is unthinkable that we could feed the world population by the ancient technique of hunting and gathering. Centuries have gone into the inbreeding of our currently used agricultural plants and animals. Most importantly agriculture has been successful because it received broad public support. Agricultural subsidies started 4–5 decades ago in the US during the dust bowl days. Today food produced by environmentally safe methods receives strong public support. These advances are due in large part to the creation of agricultural science in our Land Grant Colleges. Hybrid corn, the greatest genetic engineering feat of all time, is not only feeding the world but is being continuously modified without risk and without regulations [1].

Congressman George E. Brown, of California, laid out the challenge [2] for those of us who believe that the quality of our national life is now inescapably tied to science and technology. “We should place scientific literacy very close to the top of our priority list in improving the conditions of science in this country. A scientifically literate public and scientifically literate Congress would do more for the health of science than anything else we could do.”

Congressmen Brown went on to caution us about the misunderstanding and misuse of science he sees in the
halls of government—especially the disturbing use of scientific uncertainty as an excuse for inaction on pressing environmental issues. “There is a political and social price to pay for the deep gulf of misunderstanding that separates science from the rest of society. Science in America is also paying a price. If we are going to successfully confront the challenge of the coming decade, we are going to have to find a way to integrate rational scientific discourse into the political process.” We need to remind ourselves that the real issues we must focus on include:
- protecting our environment;
- the need for sustainable resources;
- the leveling of the food supply in the face of continued population growth;
- the depletion of our fossil reserves;
- the problem of reemerging diseases.

In addressing and prioritizing these issues, the public plays a key role in determining public policy. Value is added when the public is involved in public/science issues. It is important to recognize that there are different types of understanding. Science wants experiments to justify its positions whereas the public wants credibility for its use of its financial resources. Finally, acceptance of policy by the public does not necessarily mean public acquiescence. We will explore this relationship concerning the use of genetic enhancement to enrich our fish stocks to respond to the world crises in fish availability:
- employment;
- ecological depletion;
- moving away from diversity.

2. World wide crises in availability of fish

2.1. Population growth limited by food supply

The recent United Nations International Conference on Population and Development underscores the urgency of the United Nations world population statistics and estimates for future growth. The number of human beings in the world now totals nearly 6 billion, and the population is growing by 94 million annually [3]. It takes only 12 years to add another billion people to the population. It is likely that there will be 10 billion people by the year 2050. A growing world population will need increasing amounts of food, including high quality protein, to avoid an increase in the incidence of starvation and malnourishment. While some think that the world's food supply is sufficient, everyone agrees that the more serious question is how it is distributed. The earth's population carrying capacity is largely determined by the availability of food. Robert W. Kates, first Director of the Feinstein World Hunger Program at Brown University, wrote [4] in 1995 that “there is only enough food produced at present to meet the nutritional desires of about three-quarters of the world’s present population”. In an earlier National Research Council's Board of Science and International Development [5] the committee found that: (i) doubling food aid over present levels of about 10 million metric tons per year would be necessary to meet projected market needs throughout the decade of the nineties; and (ii) projected nutritional needs estimates are much higher: a quadrupling (or more) over present levels could be needed by the year 2000.

The world food supply has not followed the Malthus hypothesis — that the world’s natural resources could not assure that expansion in food supply would match population expansion. Whereas this theory applies to many regions of the world several decades ago, only underdeveloped countries where technology has not been effectively advanced and utilized (as it has been recently in parts of Asia) — are still at risk and fit this hypothesis. Maize production, for instance, in China, West and central Africa, Ghana, and Mali have improved significantly, providing for populations with heretofore-undernourished people and malnutrition children. This does not apply, however, to countries such as Sub-Saharan Africa, Pakistan, South Asia, India, and Bangladesh — where food demand far outstrips food supply (in general). In these developing countries, in particular, despite lower population projections through year 2020, Table 1 illustrates that the percentage of malnourished children remains high (37.1% for South Asia; 45% for Bangladesh; 24% for the Sub-Sahara Africa region). Thus projected slow improvements in per-capita food and calorie availability in the region will not be adequate to reduce child malnutrition. Therefore, despite the relative improvement in food supplies on a worldwide basis, the reduction in the absolute numbers of malnutrition children (Table 2) will still leave 30 million by year 2020, particularly in this age sector (0–5 years) in Sub-Saharan Africa and South Asia [6]. A key factor is the distribution of the food.

Higher income countries will generally be able to allocate foreign exchange for needed food imports to fill gaps between production and demand through commercial imports (such as China East Asia) — but poorer countries may be forced to allocate foreign exchange to other uses and thus might not be able to import needed foods. The income gap between the rich versus the poor will only increase. This is particularly true for fisheries and fisheries products. Developing countries produce more fisheries products than developed countries, and have since 1984 (because of the relative over-fishing, over-exploitation of marine resources in developed countries) [7]. Because of this situation, and the fact that these developing countries have either bought or have been given fishing gear from
developed countries (in the demise of their own natural fisheries) — these developing countries have become net exporters of fisheries products, because of raised prices and increased demand in the developed countries who can afford it. This then makes the fisheries foods largely unavailable to the developing countries (because of higher prices and export status), as well as creating a situation of over-exploitation of fisheries in these countries as well. Thus there is a direct link concentrated wealth and fisheries crises.

2.2. Dependence of developing countries on supply of fish

It has been estimated that about one billion people rely on fish as their primary source of animal protein. This is particularly true of developing countries (Table 3) where fish average 25% of total animal consumption. In some countries (Bangladesh, Malawi, the Pacific Islands, and Philippines) fish supply 75% on the total animal protein. In many of these countries, the capture fisheries is a crucial, if not the only, source of afford-

Table 1
Percentage of malnourished children in developing countries, 1990 and 2020: various scenarios*

<table>
<thead>
<tr>
<th>Region/country</th>
<th>1990 (%)</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing countries</td>
<td>34.30</td>
<td>24.40</td>
</tr>
<tr>
<td>Asia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>21.80</td>
<td>13.78</td>
</tr>
<tr>
<td>South Asia</td>
<td>58.50</td>
<td>41.37</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>65.80</td>
<td>52.85</td>
</tr>
<tr>
<td>India</td>
<td>63.00</td>
<td>45.49</td>
</tr>
<tr>
<td>Pakistan</td>
<td>41.60</td>
<td>32.40</td>
</tr>
<tr>
<td>Other South Asian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Countries</td>
<td>37.00</td>
<td>26.59</td>
</tr>
<tr>
<td>Southeastern Asia</td>
<td>23.97</td>
<td>16.58</td>
</tr>
<tr>
<td>Latin America and the</td>
<td>20.40</td>
<td>14.05</td>
</tr>
<tr>
<td>Caribbean</td>
<td>Sub-Saharan</td>
<td>28.39</td>
</tr>
<tr>
<td>West Asia and North</td>
<td>13.40</td>
<td>9.70</td>
</tr>
<tr>
<td>Africa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Source: IMPACT stimulation results. Data from [6]. Note: data cover children 0–5 years old.

Table 2
Number of malnourished children in developing countries, 1990 and 2020: various scenarios*

<table>
<thead>
<tr>
<th>Region/country</th>
<th>1990</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing countries</td>
<td>188.33</td>
<td>154.73</td>
</tr>
<tr>
<td>Asia</td>
<td></td>
<td></td>
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<tr>
<td>China</td>
<td>26.41</td>
<td>14.30</td>
</tr>
<tr>
<td>South Asia</td>
<td>95.81</td>
<td>72.94</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>11.96</td>
<td>11.46</td>
</tr>
<tr>
<td>India</td>
<td>70.86</td>
<td>47.73</td>
</tr>
<tr>
<td>Pakistan</td>
<td>9.13</td>
<td>9.90</td>
</tr>
<tr>
<td>Other South Asian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Countries</td>
<td>2.01</td>
<td>2.13</td>
</tr>
<tr>
<td>Southeastern Asia</td>
<td>15.04</td>
<td>10.40</td>
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<tr>
<td>Latin America and the</td>
<td>11.71</td>
<td>8.12</td>
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<tr>
<td>Caribbean</td>
<td>Sub-Saharan</td>
<td>28.61</td>
</tr>
<tr>
<td>West Asia and North</td>
<td>6.76</td>
<td>6.30</td>
</tr>
<tr>
<td>Africa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Source: IMPACT stimulation results. Data from [6]. Note: data cover children 0–5 years old.
Table 3
Contributions of fish to diet

<table>
<thead>
<tr>
<th>Region</th>
<th>Fish share of animal protein consumed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>6.6</td>
</tr>
<tr>
<td>Western Europe</td>
<td>9.7</td>
</tr>
<tr>
<td>Africa</td>
<td>21.1</td>
</tr>
<tr>
<td>Latin American and Caribbean</td>
<td>8.2</td>
</tr>
<tr>
<td>Near East</td>
<td>7.8</td>
</tr>
<tr>
<td>Far East</td>
<td>7.8</td>
</tr>
<tr>
<td>Asia centrally planned economies</td>
<td>21.7</td>
</tr>
<tr>
<td>World</td>
<td>16.0</td>
</tr>
</tbody>
</table>

* Data from [8].

able animal protein. Globally fish is the fifth largest agriculture product after rice, forest products, milk and wheat. Also fish products are far larger than any of the main terrestrial commodity groups (beef, sheep, pig and poultry meat). Fish production in the developing world totals about 60 million metric tons—close to the total of 70 million metric tons (MMT) for all the four animal commodities combined.

In a situation in these developing countries of fish being the preponderance of their total food consumption (e.g. more than the other food commodity groups—beef, sheep, poultry meat, combined), this net export situation has the potential of creating negative economics of scale and net deficits in fish and fish products trade.

In developing countries, depending on fisheries products such as Africa, the Far East, China (25%) and Bangladesh, Mali, the Pacific Islands, and the Philippines (75%) — this situation must be carefully monitored in that without significant protection of the regenerative capacities of existing fisheries stock; maintenance of high quality fisheries options such as in aquaculture species; protection of the integrity of the country’s natural ecosystems (e.g. coastal marshes/estuaries, rivers/streams); and a high proportion of aquaculture research—these countries will not have an adequate supply of future fisheries supplies to meet their population demands.

Table 4
World production in million metric tons

<table>
<thead>
<tr>
<th>Year</th>
<th>Catch</th>
<th>Aquaculture</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1958</td>
<td>75.2</td>
<td>11.2</td>
<td>86.4</td>
</tr>
<tr>
<td>1968</td>
<td>80.5</td>
<td>12.3</td>
<td>92.8</td>
</tr>
<tr>
<td>1978</td>
<td>81.2</td>
<td>13.2</td>
<td>94.4</td>
</tr>
<tr>
<td>1988</td>
<td>84.5</td>
<td>14.6</td>
<td>99.1</td>
</tr>
<tr>
<td>1998</td>
<td>85.0</td>
<td>15.1</td>
<td>100.1</td>
</tr>
<tr>
<td>1999</td>
<td>82.2</td>
<td>15.7</td>
<td>97.9</td>
</tr>
<tr>
<td>2000</td>
<td>80.5</td>
<td>17.3</td>
<td>97.8</td>
</tr>
<tr>
<td>2001</td>
<td>79.5</td>
<td>19.8</td>
<td>99.3</td>
</tr>
<tr>
<td>2002</td>
<td>79.4</td>
<td>22.8</td>
<td>102.2</td>
</tr>
<tr>
<td>2003</td>
<td>84.1</td>
<td>25.5</td>
<td>109.6</td>
</tr>
</tbody>
</table>

* Data from [9].

2.3. Decline in capture fisheries

The marine catch in capture fisheries rose from 75.2 MMT in 1985, reached 84.9 MMT in 1989 and has declined slightly ever since (Table 4). The main reasons for the decline of capture fisheries are over-fishing and coastal habitat degradation through human impact. Lester Brown [10] pointed out that three natural limits now are beginning to constrain the growth of world food production: freshwater, the amount of fertilizer that existing crop varieties can efficiently utilize, and natural fish supplies. In 1994 the Food and Agriculture Organization of the United Nations (FAO) concluded [6] that “the upper limit of fisheries on conventional (marine) species. If developed countries continue to export their excess fleet capacity to the developing world, the (fisheries) system can only continue to degrade while fisheries will increase the debt of the developing world”. In 1995 they reported that nearly 70% of the world’s conventional commercial species are now fully exploited, overexploited, depleted or recovering from depletion [8]. “Over-fishing and destruction of habitat have caused alarming drops in marine populations…” and “in some cases, heavily fished species are approaching not only commercial, but biological extinction” [11].
MMT and the world is rapidly approaching this maximum. Thirteen of the 17 major global fisheries are depleted or in serious decline. The other four are either overexploited or fully exploited. All have reached or far exceeded sustainable yield. If current per capita consumption of seafood remained stable, projected consumption of seafood by the year 2000 would be 120 MMT and 162 MMT by the year 2025 [12]. At the same time, it is interesting to note that replacing 90 MMT of seafood annually would require 200 million steers or 750 million hogs [13].

3. Responding to the challenge

3.1. Knowledge gap

If the US aquaculture industry is to respond to the crises in the wild catch fishery, it can not do so as has been traditionally done in China by utilizing vast areas of its coast for marine aquaculture. Current efforts in the US will not have an impact on the capitol demand in the North Atlantic. If so, how can we respond with scientific innovation? Science has something to offer to this crisis either by increasing the number of animals for food production or release for enhancement of the wild population. While as discussed below there are scientific methods for doing this they lead to another gap-knowledge gap in which the public is left behind. Since new technologies are always suspect by the public, any strategy to introduce science based aquaculture must involve the public.

3.2. Replenishing fish supply through aquaculture

The continued and growing need for high quality protein to feed the expanding world population argues powerfully for an increase in aquaculture production. The worldwide production of finfish, shrimp and shellfish through aquaculture was 12.1 MMT in 1990. Total worldwide aquaculture, including aquatic plants, was 15.3 MMT. Aquaculture is showing continuing gains, from 12% of the total food fish supply in 1984 to 22% in 1993 [14]. Increasing yields from aquaculture have maintained the total world production at about 100 MMT (Table 4). Eleven countries produce 80% of the world’s aquaculture output, of which six are developing countries in Asia (China, India, Indonesia, Philippines, Thailand, and Bangladesh). From 1984 to 1991 aquaculture grew 26% in developed countries and 78% in developing countries. In some (China, India, Thailand) production doubled and for others (Brazil, Ecuador, Philippines, Vietnam) nearly doubled. In 1994 the worldwide aquaculture distribution in dollars was China (37.2%), Japan (13.5%), India (5.3%), Indonesia (5.2%), Thailand (4.7), and the US (11.7%) [13]. Using the more conservative seafood production in 1990 by New, [15] ASEN-EEC Aquaculture Development and Coordination Program, (84.6 MMT from wild catch and about 11 MMT from aquaculture), a NAS Report [16] estimated that, by the year 2025, aquaculture will have to produce by a total of 77 MMT of fish and shellfish annually-more than seven times its production in 1990. This is based on population projections and an expected concomitant 70% increase in world seafood demand in the next 35 years.

Through a commitment to aquaculture, the US and significant numbers of developing countries can stabilize their lack of supply of natural fish from the oceans. In the US — even though per capita consumption remains at 22 pounds of fish protein per capita per year (average), all indications are that with the move towards a more health conspicuous diet with less red meat and/or fatty foods (high in saturated fats and cholesterol), US consumers will ever more demand more and more seafood and related healthy foods. This seafood demand will, at present, not be met by natural open ocean supplies, but instead, must come from the aquaculture/mericulture production of fish, mollusks, and crustaceans. Particularly in view of the ever increasing demands developed-western countries-are making on the natural fish supplies of developing countries, these western countries must develop their own fish supplies out of aquaculture development.

In developing countries where most all of natural fish stocks have been depleted (over 70% of conventional species have been lost), there becomes an ever more increasing requirement (let alone demand because of the every increasing prices for these products) that seafood supplies be made up with aquaculture sources-particularly in countries where over 25–75% of protein sources come from seafood supplies. With the increasing demand from the underdeveloped countries, developing countries must develop sustainable supplies of their own products to meet their every-increasing domestic needs and to prevent further increases in malnutrition children.

3.3. Sustainable aquaculture

A number of non-governmental agencies are interested in environmentally sound aquaculture. The Marine Council of the World Bank is interested in certification of sound fisheries practices. The Conservation International is a group split off from the Nature Conservancy (Arlington, VA) which is interested in supporting environmentally sound medium size product development enterprises and in playing a monitoring role in South America. Finally there is an intergovernmental body, Global Environmental Facilities, formed in 1990, interested in sustainable aquaculture.
FOA has recently had a workshop — with guidelines for sustainable aquaculture. A recent meeting in Thailand dealt with guidelines and code of contact. It is hoped to have this in place by 2005 — although the US has not as yet received a copy of the proposed code. If Conservation International showed to be interested in this, working with non-governmental agencies, they could bring pressure to adopt this code.

Sustainability depends on successful reproduction of the life cycle in captivity. Numerous new techniques in biotechnology have been introduced to induce spawning, control the sex, regulate morphogenesis and accelerate growth, among others [17]. Induction of ovulation and spermination of domestic broodstock are achieved by injection or polymer implant of pituitary hormones, as gonadotropin, synthetic peptides and gonadotropin releasing hormones. As frequently one sex grows faster, sex control is possible by endocrine manipulation during early development. Smolting can be accelerated in salmonids through use of a short photoperiod, by prolactin and somatotropin in salmonids, and in larval abalone metamorphosis is acceleration by treatment with gamma-aminobutyric acid like molecules. Thyroid and steroid injections stimulate growth in a number of fish.

4. Selective breeding program

Over the past two centuries, genetic improvements have been achieved largely through breeding programs involving hybridization, selection and mutagenesis. In agriculture, breeding programs have been developed for terrestrial farm animals in most countries and terrestrial plant production is generally based on highly improved varieties. Today it is not possible to base terrestrial animal production on wild, unimproved stocks, and yet a large part of the aquaculture industry continues to do that. Trygve Gjedrem [18] believes that the current knowledge about phenotype and genetic parameters for economically important traits in aquaculture species is sufficient to start breeding programs for Atlantic and pacific salmon, rainbow trout, tilapia, catfish and several carp species. Genetic engineering is the most effective method for genetic improvement of specific traits that are controlled by single genes. The success of genetic manipulation techniques with seaweed and marine animals will depend upon the economic gains to the aquafarmers, who thus far have depended entirely on the empirical aspects of naturally occurring genotypes.

4.1. Transgenics

A transgenic organism is one whose genome contains DNA inserted from another organism or rearranged from within the same species. Transgenic technology provides a more powerful tool for the introduction of desired genes into an individual thereby altering its phenotype [19]. DNA is introduced by blastocyst injection of plasmid DNA or by microinjection (electroporated) into embryo stem cells which are then merged with early stage embryos. Both techniques produce chimeras. If the gene of interest is present in a germ line, they can be bread to homogeneity by future generations. Genes are activated to produce protein by adjacent for the genome called promoter sequences. The promoter sequences are responsible for switching on genes in specific areas of the body. While transgenic systems have long been known in mice, the study of transgenic fish is relatively new [20]. This technology has been successfully in numerous marine microalgae [21] and animal systems to alter characteristics at a population conferring temperature resistance to plants and marine animals’ growth hormone [22], antifreeze protein [23], and disease resistance [24]. Fish offer advantages over mammalian systems, including high fertility, external fertilization and many species with transparent embryos which facilitate the analysis of reporter gene expression [25,26].

Concern has been raised that the consumer would not accept transgenic fish that contain integrated heterologous DNA as food. Some countries as Norway and Germany are concerned about introducing transgenic food products into their societies. Consequently there is an active program to isolate and utilize regulatory elements that would yield an all-fish genetic constructs [22,27–29]. Hanley et al. [30] has demonstrated the usefulness of the histone H3 promoter in genetic studies in Atlantic salmon. Similarly the β-actin promoter has been developed in transgenic medaka [31].

4.2. Gynogenesis

Gynogenesis, the production of offspring from a mature female with no paternal genetic contribution, is based upon manipulating the normal cycles of reproduction usually by using irradiated sperm. Eggs from completely inbred animals can be used for a second round of gynogenesis producing true clones in large numbers. Kavumpurath and Pandian [32] used irradiated tilapia sperm and hydrostatic pressure to produce gynogens of the ornamental labyrinth fish Betta splendens. Similar results were obtained in producing gynogens with a Japanese loach [33], the cold-water salmonid Oncorhynchus mykiss [34], and other fishes including zebra fish [35]. Lutz [36] described this as a valuable tool for the improvement of production traits through controlled breeding.
4.3. Control of released species

The escape of cultured species, whether they are native or exotic, can cause ecological effects if they interbreed extensively with the wild fish populations. There have been several approaches to control this: physical containment and biological containment (growing reproductively sterile organisms).

Netpens and other open systems are prone to escapes of cultivated fish into natural waters. Secure anchoring of netpens can assist in avoiding large scale escapes during storms. Antipredator nets can reduce the escapes from damage by seals. Finally improved design of containers for cultivated fish can reduce the danger of escapes. The use of recirculating closed systems provides an alternative approach to minimize these escapes. In their recent EDF report on aquaculture [37] recommend that ponds or raceways used to cultivate fish be placed above the 100-year flood zones.

A more promising mechanism to control released organisms is to utilize fish that are sterile and therefore cannot establish wild populations or interbreed with wild fish. The common method is to manipulate their chromosomes by thermal, pressure or chemical shocks to newly fertilized eggs so that they produce three sets of chromosomes instead of the usual two. This technique has been used extensively with bivalves leading to superior growth and suppression of gamete formation [38]. Triploid rainbow trout continue to grow long after their diploid counterparts began to divert their energies to reproductive activity [39]. Similar results have been reported for the tench [40] and Atlantic salmon [41]. However triploidy has not always resulted in superior performance [42]. While triploidy is the current method of choice other techniques are being developed to produce sterility in marine animals [43,44]. A promising approach involves cloning of aquacultured fish by tetraploidizing precursor cells, combined with gynogenic induction of spawned eggs and sex reversal [45]. Cloning wild genotypes has benefits for stock enhancement, conservation, restoration and hatchery production. The ongoing breeding of tetraploids with diploids leads to sterile or partly sterile triploids.

5. How do we go about involving the public?

We readily admit that no one has the answer to how this could be efficiently accomplished. We do have some useful examples in which release to the environment and aquaculture activities have been the basis of decision making by consensus building with broad representatives of the public. These can serve as examples of how we can achieve public participation through the participation of selected publics and decision makers in addressing how science can help with the crises of the collapse of the capture fisheries.

5.1. Case study: release of recombinant DNA organisms to the environment

Present day biotechnology companies are based on the use of recombinant DNA organisms. When this new technology burst upon the scene in the mid 1970s there was considerable public debate about this technology. An elaborate discussion occurred involving the scientific and environmental communities, the public and decision makers in congress and federal agencies such as NIH, NFS, EPA. Ultimately no legislation was passed by either the House or Senate limiting recombinant DNA research. The debate did set the framework for how this research was regulated and established a mechanism for public participation that would lead to biotechnology development utilizing this new tool. This technology was allowed to develop by stages by reviewing bodies (RAC) that included public members. As data became available, the regulations over recombinant DNA research were altered. About the same time in England a GMAC committee plays a similar role as RAC. This process seemed to work and relieved public concern. Appropriate for the present discussion, the issue of the release of recombinant organisms to the environment began to emerge in the mid 1980s with the developing technology by the Monsanto Company, among others, to genetically modify commercial plants.

On May 23, 1984 Representative Albert Gore, Jr., who was Chairman of the House Science and Technology Subcommittee on Investigations and Oversight, requested that the ASM convene a national symposium to examine scientific issues involved in releasing genetically engineered organisms into the environment. He suggested that the purpose of the symposium be to help identify the scientific issues of relevance and to stimulate debate in the appropriate scientific disciplines. He further recommended that the symposium result in the publication of a collection of papers by and for scientists, a summary for a lay audience, and an overview of methods for producing genetically engineered organisms.

The meeting was a dramatic success in which molecular biologists and environmentalists, who represent the public, struggled for days before a consensus emerged. Dr Peter Day [46] remarked they (regulators) must also weigh the estimated risks in the context of a real world in which far more drastic things are done every on a global scale in the name of agriculture. In summarizing the workshop, Dr Ed Adelberg [47] concluded that “it is up to the scientists to provide the best estimates of benefits and risks and up to the regulators to weigh these estimates wisely when deciding how much regulation is needed”. The final result has been a decade of selectively introducing this technology into present day agriculture.
5.2. Oyster round table and SSWG

Sound policy is best determined when all of the stakeholders are at the table to participate in the public discussion, and when the relevant scientific and technical information, including gaps in our knowledge, are available to all. The Maryland Roundtable Oyster Mediation is a good case study. Secretary of Natural Resources, Torrey C. Brown, brought together various parties, aquaculture industry, Waterman Association, state legislators, regulators such as the Department of Natural Resources, Environmental Protection, various environmental groups, and other concerned individuals and institutions. With the assistance of an arbitration mediator, over a period of more than a year, the parties were able to communicate over complex issues and develop an action plan that sets aside three zones beginning at river mouths and going up stream. This led to a renewal of the industry in Maryland and an improvement in water quality of the Chesapeake Bay watershed. To transfer this strategy, it was thought necessary to do three things. First, identify aquaculture opportunities unique to this area, assess available technologies, address regulatory problems, and prepare educational materials about aquaculture for regulators, practitioners and the general public. Second, recognize and address major deterrents to marine aquaculture, e.g. water quality and competing uses for coastal waters. Third, involve all the relevant constituencies-public and private — in the process of developing recommendations that will accommodate all relevant views and concerns.

The Policy Center for Marine Biosciences and Technology (PCMBT) have adopted this process to establish a Sea Scallop Working Group (SSWG) to develop and promote a plan for Sea Scallop Aquaculture in Massachusetts [48]. The document resulting is an industry-driven, bottom-up blueprint for sea scallop aquaculture in Massachusetts and puts forward recommendations from the perspective of potential sea scallop farmers tempered by the advice and guidance of professional scientists, government managers, regulators, lawyers, environmentalists, and economic development specialists. A demonstration project under consideration by SSWG was a proposal to establish a nine square mile site south of Martha’s Vineyard, MA, for an 18-month experimental project involving sea scallop research and aquaculture. This proposal, by a consortium of aquaculturists, MIT Sea Grant Program and the Conservation Law Foundation was selected for US government funding. This is in federal waters and required an amendment to the Atlantic Sea Scallop Fisheries Management Plan—which was approved in February 1997 by NEFMC. This is the first permit for aquaculture issued in US Federal waters, and opens opportunities for aquaculture projects in New England federal waters.

5.3. Regional cooperation

Some problems must be solved on a regional basis. Pollution of our coastal waters and fish management does not respect our state borders. The various interrelationships between biological diversity, mariculture, and habitat degradation all are impacted by marine pollution. We have laws on the books that govern the transfer of marine animals from one state to another. Also development of a ‘value-added’ New England seafood market requires standardizing regulations in the participating states. Another consideration of regional solutions is the financial support of projects that require the funding from more than one state. An example of this is the Council on the Marine Environment, established in 1989 by the governors of Maine, New Hampshire, and Massachusetts, and the Premiers of New Brunswick and Nova Scotia. This organization was formed to both protect and utilize the Gulf of Maine. This venture was timed with the implementing of the Canadian ‘Green Plan’ and the US ‘Mitchell Bill’ (Regional Marine Research Act). Maintenance of watersheds, coastal habitat restoration, reducing pollution loads, and even supporting hatcheries may best be carried on a multistate basis.

With home rule in Massachusetts, local communities control coastal aquaculture shellfish licenses that are issued by coastal cities and towns under the authority of Massachusetts General Law Chapter 130, Section 57. This makes difficult the implementing of the Massachusetts Aquaculture Strategic Plan. The public’s lack of knowledge regarding aquaculture leads to a public perception of aquaculture as negative. Both public and private involvement are required to develop a cost efficient, industry related projects as well as to ensure that the public benefit is protected. Laws, regulations, policy, business climate, private and public initiatives in States are flexible and can be made more favorable for aquaculture. Tidal range, exposure, biological parameters, flushing rates, temperature, and native species are more difficult considerations for States to overcome.

We can learn from successful experiences in other NE States. Connecticut has developed a successful high school technical vocation program in aquaculture. NSF has recently awarded a grant to the NE Board of Higher Education to extend this training throughout New England. Maine, Washington State, and to a lesser extent, New Hampshire served as models for developing the environmental oversight of aquaculture for the Massachusetts Aquaculture Plan.

6. Involvement in genetic enhancement

We agree with the conclusions of Donaldson [17]: “if nations are able to apply biotechnology to the enhance-
ment of aquaculture production, as some developed and developing nations are beginning to do (e.g. Cuba and China), aquaculture may possibly relieve the pressure slightly on at least some wild stocks and thus facilitate their continued survival.”

The crises in the wild capture fisheries and the promise for abating this through new technologies in genetic enhancement are both too large to be ignored. We need to balance the risks with the benefits by a process in which the public is involved and has confidence. Since based upon the experience with recombinant DNA this process will take about 10 years or more, it is timely to start. It was interesting that in the International Marine Biotechnology Conferences (IMBC), that although the concept of genetic enhancement appeared in 1989 in the Tokyo meeting, it was not until 1997 in Italy that it received extensive discussion. Indeed the last two IMBC meetings have involved experts in public policy and economic development.

Discussions have pointed to the need for commonly accepted guidelines that include containment (both physical and biological) procedures to protect the public and that will also permit testing of new technologies to achieve genetic enhancement. These guidelines should be open to periodic review and subject to change as the evidence may indicate. The above case studies provide guidance about how to collect the relevant data and subject these to review. Consensus Conferences should be organized in which relevant Professional Scientific Societies (including Ecology), Environmentalist Organizations, who represent the public, appropriate government organizations and other stakeholders can meet and seek common goals. If this is successful the meetings can review and agree on the relevant facts about this new technology and the risks of the containment procedures available. Such a group could recommend risk assessment experiments for given procedures and point out areas where our scientific information is inadequate. Societies such as the World Aquaculture Association, IMBC and FOA could publish the results of such conferences so that the agreements and recommendations are subject to review. The public could be informed through newspapers, radio and TV. The Consensus Conferences should assume a responsibility to find and enlarge communication bridges to the public.

Biodiversity concerns as well as the care and husbandry of many marine animals places a premium on scientific and public access to knowledge of life cycles, distribution and health of marine animals. The worldwide distribution of marine laboratories is valuable resources for such databases. NAML in the US and the MARS network in Europe, often the public’s opportunity to see marine animals, are already collaborating in sharing such data. This effort should be encouraged and enlarged to include aquariums and their information made available to the public.

7. Conclusions

Aquaculture, as an industrial and commercial activity can make an effective contribution to worldwide nutritional, economic and environmental challenges now and in the future. However, its maximum contribution will come by taking full advantage of the science and technology-based advances in this field. Enabled by modern tools of molecular biology, commercial aquaculture has gained increased control over genetic composition of selected species affecting reproduction cycles, growth rates, disease resistance, nutrition and other aspects and characteristics. In order to fully explore the many avenues to genetic enhancement of economically significant fish stocks through science-industry interaction, increased public involvement must be part of the strategy. In this regard, the aquaculture community faces the task of engaging the public with information that is open, transparent, and understandable. At the same time the dialogue must be sufficiently balanced to disclose all issues relating to the procedures and intended and unintended consequences associated with genetic enhancement of selected fish species.

Relevant case examples cited in this article can provide helpful learning experiences on how specific publics can be brought into meaningful exchange for the purpose of enabling informed participation in policy-making affecting the pursuit of science-based commercial aquaculture.

Our challenge is to monitor and interpret these experiences and to develop uniform approaches that will permit a multi-directional flow of relevant information appropriate to each target sector of the public. Rather than to perceive the general public in terms of potential obstacles and objections to be overcome, it can be a significant potential ally in efforts to modernize science-based practices in commercial aquaculture for the benefit of consumers, the environment and the renewability of our natural marine resources.

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