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THE NEED FOR A BALANCED ECOSYSTEM APPROACH TO BLUE REVOLUTION AQUACULTURE

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The global seafood market is at a crossroads. At present, it is structurally in the Stone Age; even with all the technological advances in seacraft, nets, and sonar, it is still largely a system of capturing marine fish that resembles the pursuits of hunter-gatherer societies. However, while landings by global capture fisheries have leveled off, and many fish stocks have essentially collapsed, demand for seafood has been rising steadily, leading to the fast expansion of aquaculture.[1] Moreover, an even greater demand for seafood may be anticipated if the desertification of agricultural land and exhaustion of freshwater reserves continues.[2] Marine aquaculture, or mariculture, does not require arable land or freshwater; it stands, therefore, as the leading contender to supply the added food demand and become the next frontier for humankind's food.

Is Standard Mariculture the Solution?

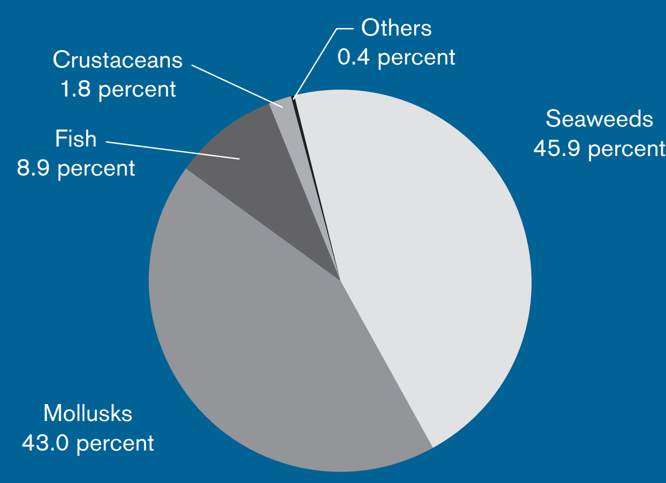
World aquaculture on land or at sea (in all water types) has been approaching parity with capture fisheries; more than 38 percent of the entire global seafood market was supplied by aquaculture in 2004.[3] Some in the industry plan to significantly increase the production of marine finfish using the "Blue Revolution" approach: modern industrialized mariculture that works with finfish in sea cages and shrimp in coastal ponds.[4]

The question is, can industrialized intensive fishmeal-fed monocultures of fish and shrimp match the rising demand? The answer appears to be "probably not"; they are ecologically imbalanced and therefore ultimately unsustainable. The overall profitability of such technologies is debatable. Arguably, to a large extent the industry's avoidance of the financial responsibility for negative environmental and social impacts has allowed for the expansion of Blue Revolution mariculture of high value finfish such as salmon and Mediterranean fish (mainly seabream and European sea bass).[5]

A great deal of research and media accounts have implicated modern mariculture for negative environmental impacts (such as pollution of the bottom below finfish seacages and coastal eutrophication) and social impacts (such as pricing "low value fish" above the means of the poor by converting them to fishmeal for "high value" finfish diets).[6] Interestingly, however, a blanket ecological criticism of the industry is not supported by the Food and Agriculture Organization's (FAO) production data: nearly 90 percent of the world mariculture production consists of environmentally friendly algae and mollusks (see Figure 1 below).[7] Nevertheless, intensive carnivore finfish monoculture, which constitutes less than 9 percent of the world's total mariculture production, has remained at the center of policymakers' attention and planning. Indeed, according to the 2006 FAO *State of World Fisheries and Aquaculture* report summary, "intensification may sustain profitability of farming operations."[8]

Various approaches have been suggested to ameliorate Blue Revolution deficiencies.[9] Countries (such as the United States, Thailand, the Philippines, and Australia), firms in the industry (such as Nutreco), intergovernmental organizations (such as FAO), and nongovernmental organizations (such as the Federation of European Aquaculture Producers),[10] have acknowledged the problems and have reacted with proposals for essential improvements—mainly in feed composition, farm management, species diversification, and farm location,[11] as well as stringent regulations and codes of conduct.[12] However, although these measures are useful, they do not sufficiently recognize that the "carnivores only" approach to mariculture is ecologically imbalanced and thus inherently unsustainable. Therefore, such measures only serve to delay the point in time when the cumulative consequences of the ecological imbalance of carnivorous fish monoculture become apparent—that is, when Blue Revolution mono-mariculture becomes impractical and possibly unprofitable due to high costs of feed and energy, environmental degradation, costly

Figure 1. Mariculture production statistics for 2004



NOTE: Total is 30.2 million tons.

SOURCE: Food and Agriculture Organization of the United Nations, 2006.

environmental monitoring and mitigation, and social disruption of displaced fishers and subsistence fish consumers.[13] The seafood markets and the mariculture industry cannot practically expand finfish farming using limited resources like fishmeal or even soy meal. To stay in business, the Blue Revolution mariculture industry must look to agricultural models—on the one hand managing its waste and on the other hand producing its own plants, mainly seaweeds. The sustained expansion of intensive seafood production inescapably requires "trophic diversification"—an ecologically balanced, combined culture of organisms of high trophic levels (carnivores) with "service crops" from lower trophic levels (mainly seaweeds and filter feeders) to perform these tasks while adding income. Moreover, cultivating crops in the sea can help conserve freshwater reserves used to irrigate terrestrial crops.

Trophically Balanced Integrated Mariculture

An example of ecological diversification of aquaculture operations is known as polyculture. This traditional and environmentally benign approach has for centuries supplied much of the world's freshwater fish and prawn markets, particularly in Southeast Asia.[14] Asian marine polyculture in coastal waters also uses wastes from cage fish farms to boost neighboring raft and long-line cultures of filter-feeding bivalves and nutrient-scrubbing seaweeds.[15]

Similar principles characterize the modern offspring of traditional polyculture: intensive culture of fish or shrimp integrated with algae and shellfish (recently described as integrated multi-trophic aquaculture (IMTA)).[16] In IMTA farms, extractive crops (seaweeds and shellfish) extract their nutrition from the effluents of fed crops (fish or shrimp). The best of such farms—whether intensive or extensive and whether in coastal waters, ponds, or tanks—balance waste production and extraction and become environmentally benign mini-biospheres.[17] The introduction of a nutrient emission tax or its exemption through the implementation of biomitigative practices would make the economic validity of the IMTA approach even more obvious. Moreover, by adopting the IMTA approach, the mariculture industry would increase its social acceptability. Although it is very difficult to assign a monetary value to such a sociopolitical variable, gaining public acceptance is imperative for the development of the industry's full potential. Also, reducing environmental and economic risk in the long term should make financing easier to obtain (the box below describes how nutrient taxes and biomitigation incentives and credits can facilitate the development of IMTA farms).

THE ECONOMIC VALUE OF INTEGRATED MULTI-TROPHIC AQUACULTURE SERVICES

Present mariculture business models do not consider or recognize the economic value of the biomitigation services provided by biofilters, as there is no cost associated with mariculture discharges or effluents in most open seawater-based systems. Regulatory and financial incentives may therefore be required to clearly recognize the benefits of the extractive components of integrated multi-trophic aquaculture (IMTA) systems (shellfish and seaweeds). A better overall cost-benefit estimate (in terms of costs and benefits to nature as well as society) for mariculture waste and its mitigation would create powerful financial and regulatory incentives for governments and the industry to jointly invest in the IMTA approach. For example, Denmark, after the initial development of finfish mariculture in the 1970s and 1980s, is now reconsidering more finfish mariculture development—with the conditions that proper planning for biomitigation and the use of biofilters such as seaweeds and shellfish must be carried out. This means that extractive species have now become part of the license to operate in Denmark and that the nutrient reduction services provided by these organisms have finally been recognized and valued for their ecosystem functions. These services need to be quantified; for example, in Denmark, the cost of remediating one kilogram of nitrogen is estimated at €33 (about US$44).[1] If laws or regulations were implemented to have mariculture operations responsibly internalize their environmental costs, a significant reduction of their profitability would occur. A study in Chile showed that by integrating the culture of the algal nutrient biofilter *Gracilaria*, the costs of waste discharges would be significantly reduced and profitability significantly increased.[2]

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2. T. Chopin et al., "Integrating Seaweeds into Marine Aquaculture Systems: A Key Toward Sustainability," *Journal of Phycology* 37, no. 6 (2001): 975–86; and A. H. Buschmann, M. Troell, and N. Kautsky, "Integrated Algal Farming: A Review," *Cahiers de Biologie Marine* 42, no. 1–2 (2001): 83–90.

The Global Significance of Extractive Crops

In principle, IMTA farms maintain a balance between the extraction of nutrients from the water by extractive organisms and the waste production by diet-fed organisms. But is the large-scale culture of extractive crops practical? Can such a system make a global impact? Seaweeds and shellfish (26.8 million tons per year; see Figure 1) in 2004 contributed 88.9 percent of total mariculture production. Globally (although often geographically separated), harvested seaweeds and shellfish remove from the sea in their valuable biomass 165,000–220,000 tons of nitrogen per year, as much as the entire nitrogen discharges of global fish and shrimp mariculture.[18] The 65 million tons of seaweed and shellfish mariculture production forecast by FAO[19] for 2050 can remove from the sea, as useful proteins, perhaps 500,000 tons of nitrogen. This would be equal to the nitrogen waste from about 14 million tons of cage-cultured salmon.[20] Thus, from the environmental pollution perspective, carnivorous finfish production can be significantly increased when balanced with extractive farms. The key point is that fed and extractive aquacultures need to be geographically coupled, which at present is often not the case. For instance, the large Chilean mariculture industries of mussels and salmon have not considered siting their respective farms in proximity to utilize the mutual ecological benefits.

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Extractive aquaculture of shellfish (as above in Ago Bay, Japan) and seaweeds represents 88.9 percent of mariculture production. Properly positioned extractive farms can create mutually beneficial, balanced ecosystems with nearby fed aquaculture fish farms.

A Call for a Shift in the Seafood Market

Shifting from fishing to cultivating inevitably entails a radical adjustment in the patterns of seafood consumption, away from the present domination of carnivorous fish and in favor of a trophically and ecologically balanced "portfolio" with more seaweeds, mollusks, herbivorous finfish, and omnivorous organisms (such as grey mullet, sea cucumber, and some crustaceans). This would be analogous to the adjustment from the hunted meat diets of hunter-gatherer societies toward plant-dominated agriculture[21] (worldwide agriculture produces 80 percent of plants and 20 percent of animal products such as meat, milk, and eggs).

In addition to being promising sources of high-value biochemicals (such as antibiotics, cosmetics, and nutritional additives[22]), phycocolloids (agar, carrageenans, and alginates), and nutritious food for other cultivated marine animals (such as abalone[23]), seaweeds and shellfish also serve as popular and healthy foods, particularly in Southeast Asia.[24] Both are sources of healthy marine omega-3 fatty acids.[25] With further research and development and strain breeding, many new uses could be found for seaweeds, and they could even replace much of the fishmeal employed to supply carnivorous fish diets with balanced proteins and oils.[26]

Do We Have the Technology?

IMTA is not only logical but also quite practical. The basic scientific and technological problems in modern integrated mariculture have been identified, and many of them are being resolved.[27] Effluents from land-based and open-water mariculture operations are suitable for extractive crops. The main factors that can determine culture design and functioning in commercial IMTA farms are being defined and quantified. Seaweeds and bivalves have significant capacity to reduce nutrient concentrations in effluents, converting in the process large quantities of nutrients into useful biomass and improving additional water quality parameters. The functioning of IMTA systems is understood sufficiently enough for the results to be extrapolated to larger-scale cultures. Research and development of commercial farms on land has been most successful in this respect, and work is under way with open cultures, particularly at large commercial scales,[28] addressing the biology, engineering, operational protocol, product quality and safety, and socioeconomics of the technology. Additional factors that may limit the growth and various aspects of the quality, temporal variations, and economics of extractive crops are currently under study, especially for closed recirculating IMTA systems.[29]

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*At the Haga Haga Farm, 70 kilometers from East London on South Africa's southeast coast, effluent from covered tanks containing the mollusk abalone (*Haliotis midae*) (left) flows into shallow seaweed (*Ulva lactuca*,* U. rigida*, and* U. fasciata*) raceways, serving as source water.*

Commercial seaweed-abalone or microalgae-shellfish pond farms currently operate, some fed by fish waste, in Australia, China, Israel, South Africa, and Thailand, while fish-shellfish-seaweed coastal farms operate in China, Chile, and Canada.

The available information about large-scale IMTA farms—particularly with respect to engineering, interactions between farmed organisms, and interactions between these organisms and the natural flora and fauna—should be increased and verified under a larger variety of climates and water conditions. As mentioned above, the practicality of using seaweeds as the source of proteins and oils in vegetarian diets for marine carnivorous finfish is an additional area that needs extensive research and development.

If we accept that, according to FAO, a doubling of capture fisheries and global aquaculture production will be necessary in the next few decades to satisfy the growing human demand (approximately 100 million tons of additional production), it can be calculated that 1 million hectares of IMTA pond farms—stocked with the seaweed sea lettuce (*Ulva lactuca*), the mollusk Manila clam (*Tapes philippinarum*), and the fish gilthead seabream (*Sparus aurata*) with an annual yield of 100 metric tons per hectare at a 1:2:1 live weight yield ratio[30]—would be enough to address this demand. It should be recognized that this is only an example and that world aquaculture production will not be based only on these three species cultivated in ponds in temperate warm regions; society demands diversification in aquatic products (including those from seawater, brackish, and freshwater environments) and the development of aquaculture in different climatic regions. However, these calculations demonstrate that, with present technology, IMTA is a valid sustainable solution if aquaculture practitioners and society decide to move toward ecologically balanced practices.

Implications for Policymakers

The logic of ecologically balanced mariculture has been gaining a consensus position in recent major books and at aquaculture conferences.[31] Well thought-out governmental and UN policies based on sound ecological principles are now necessary to usher the seafood markets in their unavoidable adjustments toward an ecological balance. The crossroads at which the seafood market may soon find itself calls for a major paradigm shift in the minds of policymakers, scientists, and industry leaders, as well as for the education of consumers to promote awareness and attitudes toward the new paradigm in seafood production. Capital is required to fund research, development, and incentives for all facets involved with seafood, including production, processing, trade, marketing, and consumption. Simple regulations could be led by tax incentives, "polluter pays" fees and specific mariculture nutrient biofiltration credits. Such measures would reduce economic and social hardships that may develop as the seafood supply evolves from fishing to farming.

We need to progress from the limited perspective of ultimately unsustainable fish and shrimp monocultures to a balanced ecosystem approach that respects the environment and includes seaweeds and shellfish as healthy and valuable products of each fish and shrimp farm. Perhaps only then can the world prepare itself for moving the seafood market out of its Stone Age state and into the twenty-first century.

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NOTES

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4. FAO, note 1 above; and K. White, B. O'Neill, and Z. Tzankova, *At a Crossroads: Will Aquaculture Fulfill the Promise of the Blue Revolution?* (Silver Spring, MD: SeaWeb, 2004), http://www.seaweb.org/resources/documents/reports_crossroads.pdf (accessed 6 February 2007). Industry, multilateral development banks, and UN agencies usually proclaim the "Blue Revolution"—referring to the monoculture of high-value species (mollusks, crustaceans, marine fish, and salmon)—to supply international markets. See A-R. Martinez, "Engineering the Blue Revolution," *Samudra: Triannual Report of ICSF*, May 1998, 45–55.

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13. "The Promise of a Blue Revolution—Fish Farming," *The Economist*, 9 August 2003, 20–23.

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