Marine aquaculture, or mariculture, has the potential to increase food security, reduce pressure on wild fish stocks and contribute to sustainable development worldwide. However, many current mariculture practices are detrimental to wild fish stocks, the marine environment and coastal communities.

Status and Trends

Aquaculture is the fastest-growing animal food-producing sector with average worldwide growth of 6-8% per year[1]. In 2006, total production from fish farming was 51.7 million tonnes, making up 47% of the world's fish food supply[1]. Globally, China is the leading producer, followed by the rest of the Asia/Pacific region, Europe and Latin America[1.] Marine fish and shrimp make up a small proportion of world aquaculture production (18%) but nearly half of the economic value[1]. In the past 30 years mariculture has grown at a faster rate than freshwater aquaculture, with production quadrupling from 5 to 20 million tonnes between 1990 and 2006[1,2].

Challenges of Mariculture

The majority of marine fish farming is large-scale monoculture that can have significant negative impacts on the coastal and marine environment[3,4]. Though lower-impact marine species such as molluscs and seaweeds dominate mariculture production[5] (81%)[6], finfish and shrimp mariculture has grown rapidly over the last 30 years and has generated serious environmental and social impacts[1]. Unsustainable inputs such as feed and fuel, polluting effluents and large spatial requirements are serious obstacles which need to be addressed in order to achieve sustainable mariculture.

Piscivorous (fish-eating) fish and shrimp farming have increased in response to market demand from developed countries. Unlike the culture of herbivorous species or filter-feeding molluscs, **piscivorous fish farming does not provide a net contribution to food supply as it requires wild-caught fish for feed.** Two to five times more protein is required to feed these species than is produced by the farmed product, putting pressure on wild fish stocks and reducing the amount available for human consumption[7]. Roughly one quarter of world fish production (33 million tonnes in 2006) is converted into feed for aquaculture and livestock[1]. Fishmeal and fish oil are mainly produced from small pelagic fish such as sardines, anchovies or mackerel[7]. These fish stocks play an important role in food security for many people in developing countries, and are also an important food source for predatory fish, marine mammals and seabirds[7,8]. Depletion of this resource can have profound ecological and human consequences. The growing demand for fishmeal and fish oil as mariculture feed has been offset by a reduction in the amount used for livestock feed[1,8,9]. However, demand is expected to outstrip supply by 2050, after which any further growth of the sector will rely on catching more fish, diverting more wild-caught fish away from human consumption, or finding alternative feed sources[10]. As feed is the largest production cost of piscivore farming, there is a strong incentive to improve efficiency and find cheaper, non-finfish protein sources[1,7]. Extensive research into plant-based protein alternatives has reduced the proportion of fishmeal and fish oil in feeds, but complete conversion to these alternatives is limited by the ability of piscivores to digest plant-based proteins[11,12].

Marine farms require space in coastal habitats. If properly sited and managed, cage mariculture can have a moderate to low impact on habitat, but pond mariculture completely alters or destroys coastal habitat[13]. Primarily used to farm finfish and shrimp, pond mariculture is responsible for an estimated loss of 2 million hectares[14] or 10-35% of mangroves and coastal wetlands[13,15]. In many places, large-scale mariculture operations convert multiple-use coastal and marine environments to single-use, causing social disruption and conflict with other users of the coastal zone[16]. *Because mariculture requires significant financial capital, it often only benefits wealthy absentee landowners rather than the coastal community as a whole.* **There is an urgent need for strong spatial planning and Integrated Coastal Zone Management** (ICZM) with full stakeholder representation to alleviate and prevent these social and environmental issues.

Waste effluent from large-scale mariculture can cause serious water pollution problems[17]. Inorganic nutrients and organic waste enter the water directly and can lead to eutrophic (high nutrient) conditions in surrounding waters and may eventually result in anoxic conditions lethal to most marine life[17]. Toxic pesticides and chemicals used in farming also contribute to the pollution of surrounding waters[17].

A final challenge of mariculture is the introduction of non-native species. Aquaculture is a leading vector of aquatic invasive species worldwide, creating "biological pollution" with often irreversible and unpredictable ecological impacts (Naylor et al 2001). While mollusc and seaweed production is low-impact relative to other forms of aquaculture, it has been responsible for many invasions of exotic species (Naylor et al 2001).

Large-scale mariculture is still a relatively young industry that developed rapidly, initially in a regulatory void. In countries such as the USA and Norway, where mariculture industries are now well-regulated, local

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environmental impacts such as habitat loss and pollution have been minimized. However, coastal mariculture in many developing countries is not well-regulated and environmental degradation caused by mariculture can be a serious issue. These countries often lack the financial and technical capacity to establish, monitor and enforce mariculture regulations[15].

Potential of Mariculture

Mariculture is currently dominated financially by large-scale monoculture that is socially, economically and ecologically unsustainable. However, by using different culture methods, mariculture can contribute to food security, be ecologically and economically sustainable and play a positive role in coastal livelihoods.

Chinese freshwater aquaculture has followed a balanced ecosystem approach for centuries[17]. Today, this sustainable form of aquaculture is practiced in both small and large scale operations across Southeast Asia and makes up the majority of global freshwater aquaculture production[18]. In traditional freshwater aquaculture, carp and other finfish are raised in a polyculture with species from lower trophic levels such as aquatic plants and shellfish. These lower trophic level species reduce water pollution and convert fish waste into valuable products that can be used as fish feed or sold in local or international markets.

Similar types of sustainable polyculture have only recently been employed in marine waters. Small-scale, low-density marine polyculture is practiced throughout Southeast Asia. For example, many traditional forms of integrated mangrove-aquaculture systems are currently practiced in Hong Kong, Indonesia, Vietnam, the Philippines, and Malaysia (Primavera 2000). At the larger commercial level, marine polyculture, also known as "Integrated Multi-Trophic Aquaculture" (IMTA), is practised in a few locations in Asia, Chile, Canada, Israel and South Africa[19,20]. Output from these farms suggests that there is great potential to improve the profitability and sustainability of mariculture through the use of marine IMTA[4,5,18,19]. As fish feed constitutes half of the operating costs in intensive single-species mariculture, using seaweed and shellfish to convert excess feed and waste products into a secondary product improves farming efficiency and substantially reduces water treatment costs. In spite of the potential improvements in profitability and environmental stewardship with a marine IMTA approach, there has been slow uptake of this technology in the mariculture industry to date. **Governments should implement policy to promote the development and growth of IMTA within the large scale mariculture industry, while also safeguarding and promoting the spread of small-scale marine polyculture in coastal communities**. There is great potential to improve the efficiency and sustainability of mariculture by promoting both small-scale marine polyculture and large-scale marine IMTA through policies at the international, national, and local levels.

Policy Recommendations for Marine Aquaculture

Reduce mariculture's dependence on wild fish as feed by promoting the farming of non-piscivorous species and support further research and development of non-fish protein alternatives

Regulate the mariculture industry at the national level, particularly for effluent water quality, farm siting and spatial planning. Incorporate mariculture into Integrated Coastal Zone Management planning for sustainable coastal zoning and resource use. Make Environmental Impact Assessments (EIAs) and ongoing environmental stewardship a licensing condition for marine farms

Implement international measures to harmonize mariculture practices and improve the traceability of products in world trade. Such measures may include codes of conduct, best practice guidelines, certification and traceability measures, and eco-labelling.

Improve mariculture's contribution to sustainable development by promoting equitable access to resources, equitable trade in mariculture products, technology transfer and capacity building in developing countries. Coastal developing states should integrate **both large and small scale mariculture** into key planning and policy instruments such as Poverty Reduction Strategy Papers, foreign direct investment policies and rural development strategies.

Promote the expansion of Marine Integrated Multi-Trophic Aquaculture through support for research and development, and for policies that provide economic incentives to practitioners for conversion to IMTA.

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