Introduction

The culture of aquatic species within, or together with, the undertaking of other productive activities is considered integrated aquaculture. Integrated aquaculture is described in the Aquaculture Glossary of the Food and Agriculture Organization of the United Nations (FAO, 2008) as: *aquaculture system sharing resources, water, feeds, management, etc., with other activities; commonly agricultural, agro-industrial, infrastructural (wastewaters, power stations, etc.)*. In the same glossary FAO describes integrated farming systems as: *an output from one subsystem in an integrated farming system, which otherwise may have been wasted, becomes an input to another subsystem resulting in a greater efficiency of output of desired products from the land/water area under a farmer's control.*

Integrated aquaculture has been widely practised by small households in freshwater environments, mainly in Asia. A review done in 2001 on integrated agriculture-aquaculture (IAA) covered technologies ranging from integrated grass-fish and embankment-fish systems, seasonal ponds and ditches livestock-fish integration of chicken-, duck- and pig-based systems, rice-fish systems, and included a few examples in coastal areas with shrimp and in freshwater areas with prawn (FAO/ICLARM/IIRR, 2001). The study concluded, among other things, that the diversification resulting from integrating crops, vegetables, livestock, trees and fish provides stability in production, efficiency in resource use and conservation of the environment. For example, uncertainty in markets and climate is countered by an array of enterprises. Little and Edwards (2003) also provided a comprehensive review of integrated livestock and fish farming systems (mostly in Asia), however the authors warn about the trend to monoculture with intensification and concentration of both livestock and fish, with a consequent potential decline of integrated practices.

Within all integrated aquaculture practices, rice-fish farming is probably one of the oldest, demonstrating a kind of co-evolution of agriculture and aquaculture, mostly in Asia, and more recently spread to other regions (Halwart and Gupta, 2004). Rice fields provide the environment and habitat for fish and other aquatic animals while the fish contribute to nutrient cycling in the process of feeding on invertebrates and other organic particles that are produced in these inundated fields. Rice-fish farming often reduces the need to use chemicals for pest control, helping preserve biodiversity; additionally, rice-fish farming facilitates the use of existing native fish species.

However, in the marine environment, integrated aquaculture has been much less reported. Yet, in recent years the idea of integrated aquaculture has been often considered a mitigation approach against the excess nutrients/organic matter generated by intensive aquaculture activities. In this context, integrated multitrophic aquaculture (IMTA) has emerged recently, where multitrophic refers to the explicit incorporation of species from different trophic positions or nutritional levels in the same system (Chopin and Robinson, 2004). These authors distinguish it from the practice of aquatic polyculture, which could simply be the co-culture of different fish species from the same trophic level. Interestingly this practice has been defined based on pilot studies in marine habitats involving joint aquaculture of fed species, usually fish, together with extractive species such as bivalves and/or macroalgae. IMTA can also allow an increase in production capacity (for harvesting) of a particular site when regular options have established limitations.

In recent years, FAO has been working on the implementation of the ecosystem approach to aquaculture (EAA) as a way to improve the governance of the sector; *an*

ecosystem approach to aquaculture is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity and resilience of interlinked social and ecological systems (Soto, Aguilar-Manjarrez and Hishamunda, 2008). The EAA promotes the efficient use of nutrient resources as well as the opportunity of diverse products and benefits (and beneficiaries) while reducing impacts, and therefore integrated aquaculture becomes a very important practical way to implement such an approach.

The increasing use of coastal areas worldwide, coupled with the rapid growth and expansion of mariculture, has created a demand for more sustainable practices from the consumers and other users of coastal zones thus providing an opportunity for integrated mariculture. However, the rapid development of global markets calls on more specialized systems focusing on one species where intensive monoculture marine farming seems to become more widespread and favoured. Nevertheless, one of the main problems is that the practices of integrated aquaculture in marine and coastal environments are a less-known and understood, its potential have not been explored in the light of sustainability of the aquaculture sector within an ecosystem perspective. This gap is the main driver for developing this technical document, thought to provide comprehensive information on current practices and the potential for integrated aquaculture in brackish and marine ecosystems.

The reviews presented here are divided by climatic zones, rather than by regions, and consider: a) temperate mariculture including experiences and potential applications in North America, Europe, South America, Southern Africa; b) tropical coastal marine and brackishwater aquaculture; including experiences from Asia, Polynesia, Central America, Africa; c) a view of a large semi-enclosed ecosystem, the Mediterranean Sea, including experiences and potential applications in Europe, the Near East and Northern Africa.

Each review provides a synthesis of the practice, major requirements for expansion and recommendations for the future development of integrated aquaculture in coastal and marine environments. The review on integrated mariculture in tropical zones involved some field work to obtain more information while the other two were prepared as desktop studies. This effort is considered a necessary step prior to the development of technical guidelines to facilitate the adoption of integrated marine aquaculture considering an ecosystem approach to the sector worldwide.

The paper on the temperate zone (Barrington, Chopin and Robinson, 2009) provides an extensive review of integrated multitrophic aquaculture (IMTA) defined as the practice which combines, in the appropriate proportions, the cultivation of fed aquaculture species (e.g. finfish/shrimp) with organic extractive aquaculture species (e.g. molluscs and macroalgae), covering northern and southern hemisphere case study countries. All countries discussed have enormous potential for IMTA growth and development although at the moment only seven present IMTA systems near or at commercial scale, most case studies are of pilot nature. The authors include a comprehensive list of algae, molluscs, polychaetes that can grow together with fed fish in different combinations and with great economic and biomitigation potential. They also suggest several steps and requirements for the expansion of IMTA in temperate zones, including establishing economic and environmental values of IMTA systems and their co-products, carefully selecting the right species, capable of growing to a significant biomass in order to capture many of the excess nutrients and remove them efficiently at harvesting time, and adequately selecting habitats and technologies for a more efficient integration. The review also highlights the need to facilitate commercialization to avoid cumbersome regulatory hurdles and promote effective legislation, regulations and incentives to further IMTA; to educate government/industry/academia and the general public about the benefits of IMTA particularly when environmental costs of monoculture are internalized; and to establish the research and development continuum to ensure success in the long term for this practice to become a widespread reality.

In the most extensive review, Troell (2009) covers integrated aquaculture in tropical coastal brackishwaters and marine environments. Tropical mariculture is a highly diverse activity, including several integrated farming practices that the author classifies into four categories: a) *Polyculture* (i.e. multiple species co-cultured in a pond/tank/cage, also including enclosure of different species; b) *Sequential integration* (PAS, partitioned aquaculture systems) on land and in open waters (differs from polyculture by the need to direct a flow of wastes sequentially between culture units with different species); c) *Temporal integration* (replacement of species within the same holding site, benefiting from wastes generated by preceding cultured species); and d) *Mangrove integration* (aquasilviculture, sequential practices – using mangroves as biofilters).

The author provides a global survey, covering almost 100 peer-reviewed articles and shows that the main objective of studies has been increasing profits from multiple species (IPMS), separately or in combination with waste mitigation (WM). Polyculture systems (60 percent) and sequential systems dominated the results of the survey, and more than 75 percent of the studies were conducted in earthen ponds; only a few were carried out in open water environments (16 percent). Shrimps were by far the dominating species group (76 percent), in combination with tilapia (29 percent) and milkfish (16 percent). Very few studies investigated integration in open waters (16 percent) and most of these included seaweeds. Although economic benefits were demonstrated in many cases, a few showed that the benefits from integration may not constitute a significant contribution to the farmer in terms of direct profits.

The author suggests that future expected increases in energy prices, costs for aquafeeds and the strengthening of environmental regulations should facilitate the implementation of integrated systems. However, if integration of e.g. fed species with extractive species (e.g. filter feeders, seaweeds) results in beneficial environmental effects – either locally through waste remediation or at a larger scale with respect to efficiency in resource utilization – such services should be internalized in order to benefit society as a whole (e.g. such as waste mitigation improving coastal ecosystem quality). In order to estimate a value for any such service, the fundamental values of ecological support systems need first to be identified and somehow valued. As Troell points out, only then it will be possible to estimate the true costs of any aquaculture production and make it more economically attractive by applying different mitigation measures (including integrated techniques, through for instance the "polluter pay principle").

Angel and Freeman (2009) deal with integrated aquaculture (INTAQ) as a way to implement an ecosystem approach to the aquaculture sector in an enclosed ecosystem, the Mediterranean Sea. This review does not provide extensive information on the current integrated practices (mostly inexistent) but focus on its feasibility and potential in an environment relatively poor in nutrients. Here the utilization of the additional nutrients provided by fed aquaculture is an added value of integrated aquaculture. However, Mediterranean Sea coastal zones in general have very high competing demand for tourism and mariculture practices are periodically challenged due to potential environmental impacts affecting tourism. In fact, the European Environmental Agency lists aquaculture as an important potential cause of environmental deterioration in the region if it is developed in unregulated and inappropriate modes. The authors mainly address four issues: to what extent INTAQ permits natural adjustments at the ecological level; how does INTAQ compare with alternative uses of the same environment; given the fact that there is intense competition for coastal and marine resources, where does INTAQ fit in terms of regional priorities; and what are the technical, production, investment, and regulatory challenges as well as opportunities for this practice in the Mediterranean Sea.

This review also emphasizes the practical constrains regarding legal frameworks of an ecosystem shared by several countries. In order to realize the potential of INTAQ, more information is needed on most aspects of the practice. Research and commercial scale

experience is required. Information on the potential risks and returns to investment will be especially important in order to facilitate entry at the enterprise levels. The authors also underscore the urgent need to disseminate information on the environmental and broader social implications of INTAQ in order to counter prevail scepticism and negative attitudes toward mariculture in general and INTAQ in particular.

SUMMARY

Integrated marine aquaculture can cover a diverse range of co-culture/farming practices including IMTA to the more specialized integration of mangrove planting with aquaculture, called aquasilviculture. Clearly, integrated aquaculture has many benefits, where bioremediation is one of the most relevant and yet unvalued in its real social and economic potential. Reducing risks is another advantage and profitable aspect of farming multiple species: a diversified product portfolio will increase the resilience of the operation, for instance when facing changing prices for one of the farmed species or the accidental catastrophic destruction of a crop

All the authors highlight the need to develop modern integrated mariculture systems, which are bound to play a major role worldwide in sustainable expansions of aquaculture in the sea, within a balanced ecosystem thus responding to a global increase for seafood but with a new paradigm in the design of more efficient food production systems. Another important message from the three reviews is that a successful integrated mariculture operation must integrate all stakeholders into its development plan: government, industry, academia, the general public and environmental NGOs must work together and the role of integrated aquaculture within integrated coastal zone management plan must be clearly defined. The three reviews underscore the need to facilitate commercialization and promote effective legislation for the inclusion of integrated aquaculture through adequate incentives. This becomes particularly relevant when considering environmental costs of monoculture farming. Bioremediation of fed aquaculture impacts through integrated aquaculture is a core benefit but the increase of production, more diverse and secure business and larger profits should not be underestimated as additional advantages.

In many cases, more research is needed to further integrated aquaculture – particularly regarding the technical implementation of a farm. At this level, an important issue is to adopt adequate management practices that avoid or reduce the likelihood of disease transmission within and between aquaculture facilities or to the natural aquatic fauna. Also, careful consideration should be paid to the selection of species used in polyculture or integrated multitrophic aquaculture to reduce potential stress and suffering of culture individuals. Integrated aquaculture should be looked upon as a very important tool to facilitate the sustainable growth of marine aquaculture and its potential to promote sustainable development.

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