there has been a shift from species (e.g. marine mammals) or sectoral (e.g.: fisheries) emphases towards a focus on functional integration with agreements on protection of marine environments and the establishment of marine protected areas. Also, over time, agreements have increasingly recognized the challenge presented by complex, dynamic, multifunctional environments, the wide variation among ecosystems in terms of size and composition, and the importance of sustainability. In varying degrees these approaches emphasize the needs of human beings; the preservation of resources for future generations and precaution in the face of risk and uncertainty. Many of the recent provisions itemized in the Appendix, such as the Code of Conduct for Responsible Fisheries and MARPOL include clauses specific to fish farms, especially sea-based farms. FAO (2007) applies the following definition to aquaculture:

> *An ecosystem approach to aquaculture (EAA) strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems including their interactions, flows and processes and applying an integrated approach to aquaculture within ecological and operational meaningful boundaries.*

In order to apply this definition, a clear set of principles and outlines must be developed. One such example can be found in the ecosystem approach to fisheries (EAF). Garcia *et al.* (2003) provide a very thorough review of the foundations of the EAF. It includes several definitions currently in use, principles and operational guidelines that are relevant for aquaculture as well as capture fisheries. The issues of scale and complexity are key features as are the risk, risk reduction and the promotion of the Precautionary Principle. These last three are particularly important for INTAQ as a relatively new set of practice, offering potential benefits compared to the industry standard, but still facing many uncertainties.

In their definition, Garcia *et al*. (2003) focus on complexity and interaction. The ecosystem is defined as "a system of complex interactions of populations between themselves and with their environment" or as "the joint functioning and interaction of these two compartments (populations and environment) in a functional unit of variable size" (Odum, 1975; Nybakken, 1982; Scialabba, 1998). "Populations" include people, in particular people involved in the industry. In addition to complexity and interaction, ecosystems must be considered at different geographical scales, from "a grain of sand with its rich microfauna, to a whole beach, a coastal area or estuary, a semi-enclosed sea and, eventually, the whole Earth". Lackey (1998) observes that ecosystems are defined by scales of observation, "from a drop of dew to an ocean, …from a people to a planet". Ecosystems are nested, consisting of smaller ones within larger ones, each exchanging matter and information with others. Efficient management of ecosystems involves mapping them and this can be a major challenge since their geographic boundaries are not always easy to determine, given their dependence on scale, function and processes; especially processes that change with time. For example, seasonal variability is often higher in the pelagic than in the benthic domain and this is significant for aquaculture-environmental interactions. More recently, FAO proposed the farm, the watershed or relevant water body and the global market as the most relevant scales (Soto, Aguilar-Manjarrez and Hishamunda, 2008).

Analytic framework

In order to apply the ecosystem approach to aquaculture and to set up the proper context for INTAQ in the Mediterranean Sea, it is necessary to incorporate some of the above definitions and concepts into a practical analytic framework. For INTAQ and its complex ecosystem interaction we use three conceptual tools: carrying capacities, zones of influence and level of impact (primary, secondary and tertiary). Mc Kindsey *et al.* (2006) and Inglis, Hayden and Ross (2000) applied the concept of carrying capacity to consider the physical, biotic and human aspects of the ecosystem and the interaction among them to the assessment of bivalve culture. They used four categories of carrying capacity that can be very meaningful when designing INTAQ within the ecosystem's perspective:

1. physical carrying capacity;
2. ecological carrying capacity
3. production carrying capacity, and
4. social carrying capacity.

The first refers to the non-biological, physical features such as type of substrate, depth, hydrodynamics, temperature and salinity and their relation to the target species. It determines such things as the size of the farm and specific engineering requirements with respect to the physical conditions of a given location.

Ecological carrying capacity is defined by thresholds of viability for ecosystem functions and other definitions of "acceptable" ecological impacts. Spatially, it can refer to the immediate area of the farm or larger spatial/ecological units. Some of the ecological impacts of most concern, especially in monoculture, are those resulting from farm effluent (i.e. uneaten food, faeces, and metabolic waste) on the water column and benthos. Very delicate or unique ecosystems will have the lowest carrying capacity or tolerance for perturbations as these may cause irreversible change. Similarly, areas already subject to urbanization, recreation and other pressures will also have a lower capacity to handle additional perturbation.

The *productive carrying capacity* describes the ways in which the physical and ecological carrying capacities determine the potential level of production. For example, if the ecological carrying capacity of potential inshore sites requires very low levels of effluent, then the operator must consider a combination of effluent treatment options, including INTAQ together with alternative site selection options. In the case of alternative sites, there are clear tradeoffs between ecological, physical and productive carrying capacities. While the higher flow-through gives alternative less protected sites a higher tolerance for effluent, it may impose restrictions on the type of culture that is feasible; for example, exposed offshore sites may be unsuited to the cultivation of many macroalgal species that are not adapted to withstand rough seas.

Social carrying capacity reflects the tradeoffs among all stakeholders using common property resources. It is the most difficult of the four to quantify but the most critical from the management perspective because if there is widespread opposition to aquaculture in general and INTAQ in particular, the prospects for its expansion will be limited.

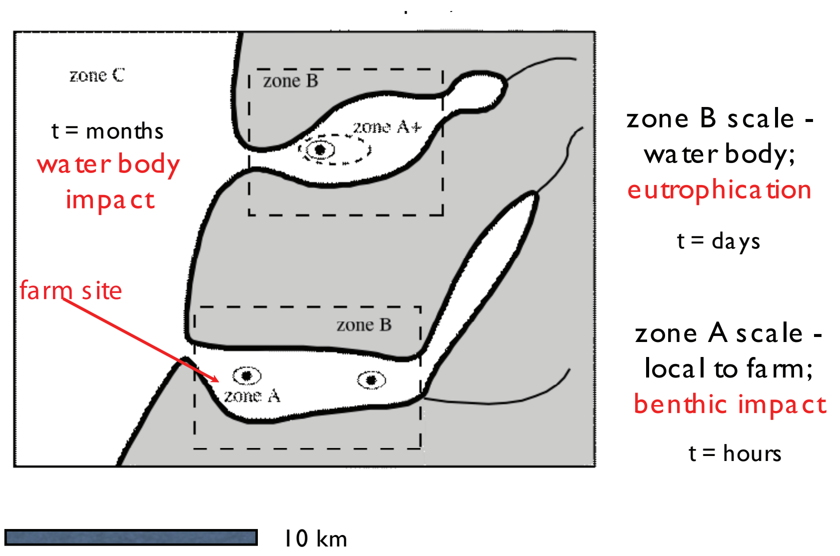
Another conceptual tool that this report uses is the differentiation among primary, secondary and tertiary impacts. This allows us to describe effects in terms of their duration or longevity[3] and their zone of influence[4] (AMEC, 2002). This conceptualization is a useful complement to the carrying capacity framework because it permits the tracking of a given event (e.g.: farm waste, escaped fish, urban pollution) through time and space in a dose-response format that accounts for downstream effects and feedback mechanisms. Many of the primary impacts pertain to the productive carrying capacity, in particular, at the farm level. For example, farm effluent is a primary impact that depends on the type of culture, design and management of the farm. These discharges may physically smother organisms living on the sea floor and rapidly change the biogeochemistry of the surface sediments. The release of nutrients into the water may increase primary productivity and in some extreme cases

[3] Duration or longevity refers to the length of time that an effect is in evidence or the amount of time that is needed for an ecosystem to recover. For example an impact may be reversible over the short, medium or long-term; it may be permanent or irreversible; it may be cyclical or seasonal.

[4] Zone of influence refers to the impacts over space i.e. near-field/immediate vicinity of farm or far-field/ surrounding environment.

FIGURE 2
Scales: spatial extent and time scale

(ecosystem scale considered must be relevant to scale of the farmacy and impact)



Source: modified from Tett (2007).

lead to problems such as algal blooms. The severity of secondary impacts such as these, affecting the quality of the benthos and water column, depends largely on the ecological carrying capacity of the site and its zone of influence. The physical carrying capacity is also relevant in that hydrology influences the rate at which effluent is dispersed. Tertiary impacts tend to be more relevant for the social carrying capacities. For example, changes in environmental quality (and perceptions of these changes) that affect different stakeholders will determine the social acceptability of aquaculture. For example, monoculture aquaculture in Europe and North America is often perceived to be a source of pollution. Ridler *et al.* (2007) have shown that when people are informed about the environmental improvements offered by INTAQ they have a much more favorable attitude toward the practice. The secondary effects may also occur further afield, especially if they are the result of cumulative effects of several farms concentrated in a given area. In Figure 2, Tett (2007) provides a useful, complementary diagrammatic conceptualization for the three levels of impacts over space and time.

The scales, Zone A, Zone B and Zone C correspond closely to the extent of primary, secondary and tertiary impacts. Zone A, the farm location is the area most subject to primary impact. In the example above, benthic and water quality secondary impacts from farm effluent occur almost immediately after discharge and are restricted to a well defined area close to the farm. Water body or Zone B impacts and regional or Zone C impacts affect larger areas, and generally take more time and potentially affect more components of the ecosystem and stakeholders. This conceptualization is especially relevant for the different configurations in which INTAQ can occur. In the case of IMTA, Zone A, and its interaction with Zones B and C are key. In contrast, if INTAQ is the result of several farms operating in proximity to one another, then the ecological integration and production enhancements must be considered not only for the individual farm but over the water body, or Zone B in which the farms operate.

In implementing INTAQ within the ecosystem approach framework we have used three questions as a guide:

- First, to what extent does INTAQ permit natural adjustments? That is, to what extent are changes permanent and to what extent do they alter the natural ecosystem? For example, it has been suggested that even large changes in the water column and benthic environments around cages can be managed by introducing a farming cycle that includes fallow periods (Pearson and Black, 2001). If INTAQ has a smaller ecological footprint, it is possible that the need for fallow periods may be reduced

- Second, what is the relevance of each carrying capacity to the main issues of concern for INTAQ in the Mediterranean Sea region? As we have noted, in several important respects, INTAQ is more consistent with the ecosystem approach than monoculture. This is especially true in terms of ecological carrying capacities. In terms of the social carrying capacity, INTAQ shares many issues with monoculture. Restrictions on site selection in the congested coastal areas of Turkey illustrate the limits to the social carrying capacity. Aquaculture sites have come into increasing competition with the Turkish tourist industry for coastal habitats and the result has been that many farms have been forced to relocate to sites of the coast or far offshore (G. Yucel, pers. comm.). The offshore requirement can be restrictive for certain types of INTAQ. If, for example it involves the culture of macro-algae, the rougher waters can damage both the infrastructure and the plants themselves. Instances of conflict over the location of nearshore cages in the face of increased demand for other uses of the coastline are common throughout the Mediterranean Sea region. Similarly, urban sewage and industrial effluent and their effect on water quality in and around cage farms have clear implications for INTAQ operations. The costs and benefits of potential sites must be considered in terms of the full range of interactions and the resulting costs and benefits.
- Third, how does INTAQ compare in terms of impacts with alternatives? The main alternative considered in this report is monoculture but the list of candidate alternatives is long, and need not be restricted to aquaculture. In principle, comparisons could be made among all possible competing (though not necessarily mutually exclusive) uses of coastal zone and marine resources in which INTAQ takes place in order to obtain an indication of which use(s) or combination of uses offer the highest value to society. This type of assessment would also require the application of common metric(s) (e.g. physical, monetary or other ranking) and is beyond the scope of this study. We therefore focus on a quantification of primary impacts in the ecological carrying capacity and a qualitative description of impacts and interactions in the other three carrying capacities with reference to secondary and tertiary impacts.

MEDITERRANEAN SEA

Description of the ecosystem

The Mediterranean Sea is a large semi-enclosed, saline sea bordered by 22 countries[5] and having two distinct basins divided by a narrow (150 km), relatively shallow (400 m) channel between Sicily in the north and Tunisia in the south (see Figure 2 below). The areal division of the sea between the western and eastern basin is approximately 1/3: 2/3. The eastern basin is somewhat more saline than the western basin, especially in the vicinity of the Suez Canal. On the whole, the Mediterranean Sea is considered oligotrophic (though some limited regions and coastal areas, such as parts of the northern Adriatic, may be eutrophic), however it is warmer and more oligotrophic in its southern and eastern areas. While the sea accounts for one percent of the world's total marine area, it contains six percent of the world's marine species with

[5] The countries bordering the sea are, Albania, Algeria, Bosnia and Herzegovina, Croatia, Egypt, France, Greece, Israel, Italy, Tunisia, Lebanon, Libyan Arab Jamahiriya, Monaco, Montenegro, Morocco, Slovenia, Spain, the Syrian Arab Republic and Turkey. Island States within the sea are Cyprus and Malta.

FIGURE 3
Mediterranean Sea and its basin

over 400 endemic species of fish, shellfish, corals, sponges and seaweeds with greater diversity in the western basin (EEA, 2006). Notwithstanding this large variety, overall biomass is relatively low because of the low level of phytoplankton production.

Box 1 provides an ecological summary of the Mediterranean Sea proposed by the European Environment Agency, EEA (2006).

In terms of human settlement and uses of natural and environmental resources of the Mediterranean Sea, 82 million people live in coastal cities and 32 percent of the population lives in North Africa. Levels of development vary widely over the region. Population growth in urban and southern areas is the highest in the region. Tourism brings over 100 million visitors to coastal areas annually and is a major source of seasonal population pressure. Tourism is a major competing sector with aquaculture.

BOX 1
Main ecological characteristics of the Mediterranean Sea

- high temperatures/metabolic rates
- high salinity
- microtidal/low renewal rates: tides are typically less that 40 cm creating low potential for dilution and dispersion of dissolved and particulate waste
- oligotrophic: high oxygen concentration, poor in nutrients; low primary production and low phytoplankton biomass. Increasing oligotrophy from west to east; primary production in the open sea considered to be phosphorous limited, not nitrogen limited as is the case in most seas
- rich in biodiversity, especially in coastal zones with high rate of endemism
- biological invasions: main entry points: shipping ports; lagoons; and Suez Canal causes higher incidence of alien species in the eastern basin;

Source: EEA, 2006, p. 10

In addition to the above land-based uses associated with urbanization, tourism and industry, the sea is a major shipping route and base for capture fisheries and mariculture. There are 75 marine protected areas (MPA) in the region. The designation applies to specific unique or threatened resources, in need of protection such as *Posidonia oceanica*, sea grass beds and breeding and nesting sites for endangered species such as the loggerhead sea turtle (*Caretta caretta*). MPAs were also designated to encourage specific uses such as sustainable tourism and regenerating fish stocks (MEDPAN, 2007).

Aquaculture production in the region

Although INTAQ is very rare in the region, and therefore, data is scarce and often unavailable in the public sphere. Reasonable data is available for aquaculture in general. The statistics presented below, while not specific to INTAQ are the basis for inference as to potential future developments and patterns of growth in INTAQ.

The total production of all species in the Mediterranean Sea in 2006 was estimated at about 373 thousand tonnes (FAO-FishStat, 2008) with 14 percent growth from 2000 to 2006 (Table 1). The average rate conceals considerable variability ranging from a decrease of 17 percent between 2003 and 2004, and a 34 percent increase between 2004 and 2005. As Table 1 and Figure 4a show, although the industry has grown rapidly since 1950, production is variable, with variability increasing with growth rates. As in much of the world, the growth rate of Mediterranean Sea aquaculture has outpaced that of capture fisheries. Moreover, the interannual variability in aquaculture production is lower than in capture fisheries which have clearly reached a plateau in terms of annual

TABLE 1
Aquaculture production by country: 2000–2006 (by production volume in tonnes)

Country	2000	2001	2002	2003	2004	2005	2006
Italy	167 775	169 980	146 649	149 184	84 608	147 535	139 699
Greece	92 050	93 742	84 874	98 518	94 112	102 987	109 267
Turkey	35 646	29 730	26 868	39 726	50 335	70 963	72 331
France	21 414	30 499	26 149	29 907	26 903	28 324	30 753
Croatia	3 485	5 802	5 531	5 147	6 970	6 797	8 469
Israel	2 914	3 161	3 056	3 109	3 354	3 196	2 725
Cyprus	1 800	1 800	1 782	1 731	2 084	2 317	2 549
Albania	202	264	500	1 110	1 200	1 110	1 730
Tunisia	719	955	1 111	1 227	1 250	1 542	1 548
Spain	587	805	973	781	1 678	1 266	1 500
Malta	1 746	1 235	1 116	887	868	736	1 115
Ukraine	10	95	24	236	273	626	421
Libyan Arab Jamahiriya					278	378	378
Bosnia and Herzegovina			260	260	107	251	265
Bulgaria	10		55	15	118	171	228
Slovenia	117	154	120	206	273	228	193
Morocco	697	575	792	856	815	1 224	51
Algeria	47	64	65	23	14	14	16
Montenegro							11
Serbia and Montenegro	8	9	6	8	11	11	
TOTAL	**329 436**	**338 870**	**299 941**	**332 931**	**275 251**	**369 676**	**373 249**
% annual growth		2.9%	-11.5%	11.0%	- 17.3%	34.3%	1.0%
Average Growth							3.4%

Source: FAO FishStat, 2008.

harvest (Figure 4a); these issues may prove to be important considerations for business and policy decision-makers, especially, those concerned with food security, coastal communities and development.

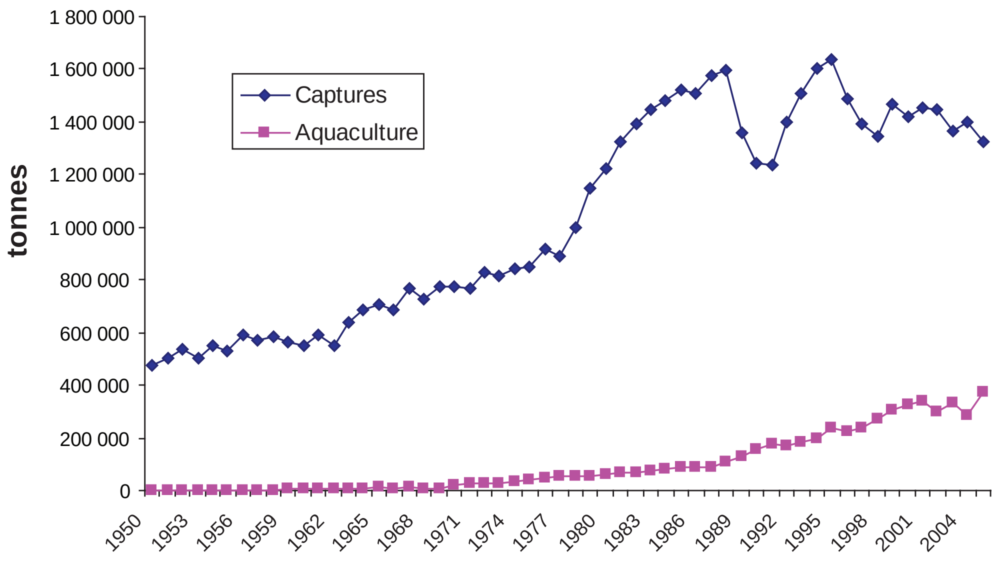
Within the aquaculture sector, the most striking feature of the physical production is the rate at which finfish have overtaken mussels as the dominant product. In 1990, finfish production accounted for less than 10 000 tonnes as compared to approximately 90 000 tonnes of mussels. In 2003, finfish production was in the range of 180 000 tonnes (49 percent) and mussels, 150 000 tonnes (40 percent). Clams and oysters had seven and two percent shares each. The main cultivated finfish species in the region are gilthead sea bream (*Sparus aurata*), European sea bass (*Dicentrarchus labrax*) and flathead grey mullet (*Mugil cephalus*). Given the rapid transformation in the industry, it is not surprising that production growth has outstripped the knowledge base and regulatory and social frameworks. Greece, Turkey and Italy were the three largest producers, with 86 percent of total production in 2006.

Key opportunities and bottlenecks for implementation and expansion of INTAQ in the Mediterranean Sea

The key opportunities for the expansion of INTAQ have much in common with the opportunities for mariculture as a whole, mainly, the stressed state of wild fish stocks and the capture fisheries (Figure 4a) and the increased demand for sea products. Both imply that the demand for the output from aquaculture, including INTAQ will continue to be high. Moreover the prospects for INTAQ to lead in the expansion of mariculture should be very good because of its better environmental potential compared to monoculture. In ecological terms, the lower effluent of INTAQ is preferred and with more experience and proper information dissemination this should lead to a higher level of public receptiveness and favourable regulatory provisions.

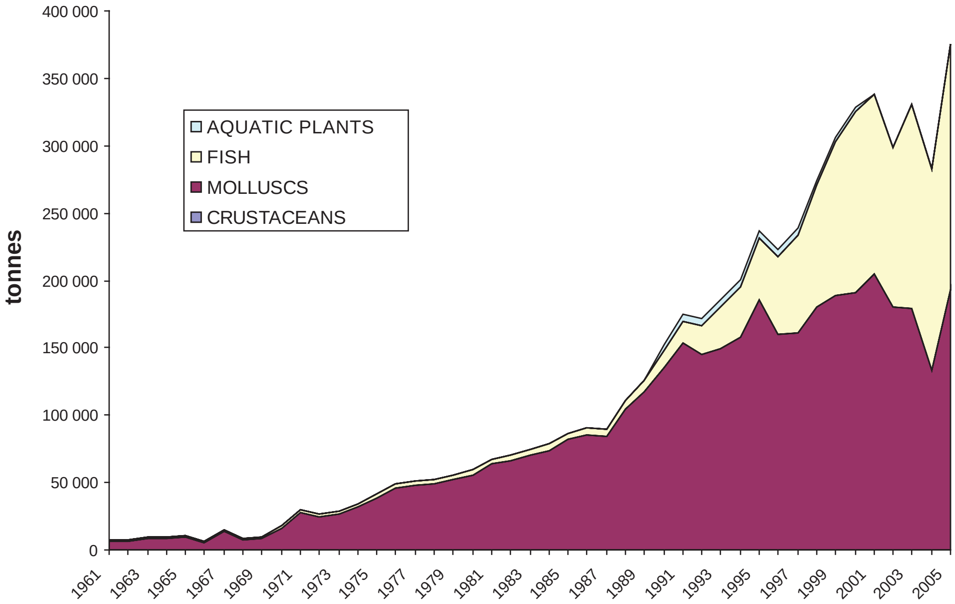
Similarly, at the investment level, the higher profit potential of INTAQ provides incentive for expansion. The main challenges, unique to INTAQ in the region are the oligotrophic conditions in much of the Mediterranean Sea. Even with the organic and inorganic effluents from fed species, the low baseline productivity may be insufficient to support the cultivation of other organisms. This implies that a careful examination

FIGURE 4a
Mediterranean Sea aquatic production from captures and aquaculture 1950-2006



Source: FAO FishStat, 2008

FIGURE 4b
Mediterranean Sea aquaculture production by product



Source: FAO FishStat, 2008.

of potential sites' baseline productivity and the contribution of aquaculture to nutrient loading are needed before conclusions can be made regarding implementation of INTAQ (Karakassis, Pitta and Krom, 2005). This leads us to the second major challenge for INTAQ and this is the general lack of experience in the Mediterranean Sea region. Though one of the reasons that there is less INTAQ in the Mediterranean Sea than in other areas of the world may be the sea's ecological carrying capacity, it may also be that INTAQ is relatively new. Even outside the region, commercial experience is limited and within the region, information on the practice is limited to a few experimental studies (e.g. Neori, Shpigel and Ben-Ezra, 2000; Neori *et al.*, 2004; 2007; Angel *et al.*, 2000a; 2002).

Other opportunities and challenges that INTAQ shares with mariculture as a whole in the region include, on the opportunity side, the potential for aquaculture operations to rejuvenate remote coastal communities, especially those formerly reliant on capture fisheries. Shared challenges include the competition for coastal space in more congested areas of the Mediterranean Sea region, poor public image and unfavourable regulatory conditions.

SYNTHESIS OF STUDIES AND REPORTS

In this synthesis, two elements are emphasized:

Description: It provides review of the current state of marine and brackish water INTAQ practices in the Mediterranean Sea including a classification of practices; an overview of production; an overview of current regulatory and legislative frameworks and guidelines; and a review of the technological requirements and site characteristics most conducive to the development or expansion of INTAQ.

***Ecosystem approach*:** The ecosystem approach, described above is the lens through which the potential of INTAQ is assessed and compared with other methods of securing sea products; including finfish, crustaceans, bivalves, other invertebrates and macroalgae. The methods include monoculture aquaculture and capture fishery. It takes into account the multiple uses of coastal and marine resources (e.g. tourism, recreation, shipping, aquaculture), ecological impacts (e.g. water quality) stakeholder issues and social/political acceptability (e.g. social perceptions, public education, etc) as well as farm, investment and industry level issues.

Classification of INTAQ practices in the Mediterranean Sea

The most common design for an INTAQ system is based primarily on the needs of the main cultured species, usually fed finfish. Modifications are made to incorporate extractive species such as filterfeeders, detritivores and macro algae, but the basic design and engineering are tailored to the cage, tank or pond requirements of the finfish. A classical and well known example of such a system is a pilot project in the Bay of Fundy, on Canada's east coast where seaweed (*Laminaria saccharina* and *Alaria esculenta*), mussels (*Mytilus edulis*) and Atlantic salmon are grown together (Barrington, Chopin and Robinson, 2009; Ridler *et al.*, 2006; Chopin and Bastarache, 2004). In this case the salmon are the focus product. Experimental, pilot and small-scale commercial enterprises of this type can be found elsewhere in Canada, South Africa, Australia, the United Kingdom and, to a much more limited extent, in the Mediterranean Sea. A less common, and promising system that integrates salmon, scallops and oysters at the design stage is proposed by Cross (2004). The objective of this system is better integration that leads to lower operating costs. At present, it is at the theoretical and early experimental level.

As mentioned INTAQ at any scale is rare in the Mediterranean Sea and in this section, we present several isolated examples of advanced experimental and pilot/near commercial scale installations. All the examples are based on extensions of intensive cage or land-based (varying intensities) finfish culture. Land-based marine INTAQ takes place in man-made ponds, race-ways or tanks, usually in proximity to a marine water body (i.e. estuary or sea). Generally, each species is cultivated in a separate pond or tank (Neori *et al.,* 2004). Open water INTAQ may take place in floating cages or in net pens anchored to the sea bed in combination with other species reared using appropriate gear such as rafts, racks, and long-lines. The floating cages or net pens provide the growth environment for finfish and the other gear enables the cultivation of seaweed and/or mollusks, bivalves and other invertebrates. If shellfish and crustaceans are cultivated, specialized net cages, racks or trays may be used. INTAQ may also use artificial substrates/reefs. Further detail on the use of artificial reefs is given in the description of close-to-INTAQ methods below.

Country overviews

Egypt

Various species of mullet, sea bream, sea bass and shrimp are cultivated extensively in the saline Lake Quarun. Total production of all species is estimated at 23 000 tonnes, with a yield of 150 kg/ha per annum. Juvenile mullet are raised in earthen ponds adjacent to the lake and fertilizer and livestock waste is the main feed input. The source of fry for all species is wild stock and this is considered a serious non-sustainable practice, especially for mullet (ICES, 2005; El Gayar, 2003; Mega Pesca, 2001).

Spain (Andalucia) and Portugal

Several pond systems with different levels of intensity are being used to raise sea bream, sea bass, mullets, eel, sole and shrimp. A total of 67 000 tonnes per annum is produced; the bulk (60 percent) is sea bream in semi-intensive cultivation. Thirty-four percent of production is intensive and the remaining six percent is reared in extensive sole/mullet/shrimp/eel cultivation. The system employs recirculation of nutrient rich water from the intensive to the extensive ponds, where the organic content provides food for worms, the main food for sole and other prey fish (ICES, 2005).

Southern France

A low production, semi-intensive operation produces shrimp and oysters in the same pond. The oysters consume the phytobenthos re-suspended by shrimp foraging, providing added product and minor biofiltration benefits (ICES, 2005).

Israel

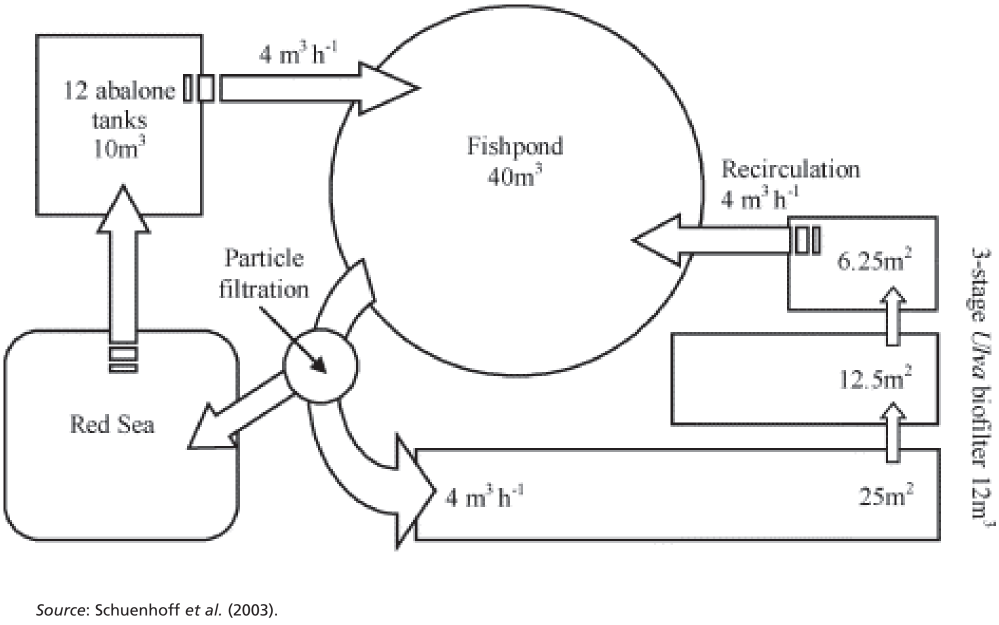
Several experimental and pilot facilities have been tested. Finfish (sea bream and sea bass), invertebrates (abalone or sea urchin) and macroalgae (*Ulva* sp. or *Gracilaria* sp.) are cultivated in separate, monoculture enclosures through which water is recirculated (see Figure 5). Primary inflow is used to raise abalone or urchin. The seabream, reared in intensive tanks using abalone or urchin effluent and the ulva is reared in raceways using sea bream effluent that has passed through a sedimentation tank. The ulva effluent can also be used to rear sea bream. In addition to its biofiltration function, the ulva is also used to feed the invertebrates (Shpigel, Neori and Marshall, 1996; Neori, Shpigel, and Ben-Ezra, 2000; Schuenhoff *et al.*, 2003). Other three-phylla, on-land systems have been designed to exploit the biofiltration capacity of seaweed, but without the "polishing" biological filter that minimises nutrient output in the final stage of the recirculating system (G. Shavit, pers. comm.).

Porter *et al.* (1996), Katz *et al.* (2002) and Lupatsch, Katz and Angel (2003) documented a series of advanced experiments in the co-cultivation of sea bream and mullet in a system comprised of mullets in benthic enclosures below floating sea bream cages. These studies have found significant improvement in sediment quality alongside production of mullets without the need for additional of manufactured feed.

Other

In Croatia, advanced experimentation has been carried out for combinations of fed finfish and mussels. After ten months of growth, differences in size were observed for mussels growing at different distances from the fish cages (Perhada *et al.*, 2007). Mussels on lines located at a median distance showed higher growth than those closest to and furthest from the cages. The study also recorded seasonal differences

FIGURE 5
On-land pond, three-phylla recirculating system schematic



Source: Schuenhoff *et al.* (2003).

in growth rates and generally provides good indications for the potential for finfish-mussel culture in the eastern Adriatic Sea. There are several other more preliminary experimental INTAQ operations that we have been unable to fully document here. These include (but are not restricted to) the co-cultivation of sea bream and sponges in Turkey, sea bream with mussels in Greece and various higher trophic finfish species with mussels in Croatia.

Polyculture and other close-to-INTAQ systems in the Mediterranean Sea region

There are several practices that share some important characteristics with INTAQ, in particular, the co-cultivation of several species. We have not classified them as INTAQ as they lack one of more of INTAQ's defining features: That is, the use of manufactured feed for higher trophic species, joint production, deliberate design and/or intervention to achieve ecological integration and environmental benefit. Table 2 gives a summary classification and description of INTAQ and similar systems in the region.

Valliculture (Italy)

Valliculture is a traditional form of brackish water, extensive aquaculture, practised mainly in the Po River delta. Current production totals about 3 000 tonnes of mullet, 1 000 tonnes of sea bream and 1 000 tonnes of sea bass per annum in 43 000 hectares of extensive estuary ponds. Fry are captured from wild stock using a weir or other physical means of separating fish from the sea. Juvenile fish are able to pass through the weir during seasonal migrations and become trapped as their size increases. In some cases, sea bream and sea bass are stocked from hatcheries. The system has been adapted for detritivore species, such as mullet (Ghion, 1986). In addition to the stocking aspect, the systems may also alter the level of salinity in the area of cultivation (Ghion, 1986; Ardizzone, Cataudella and Rossi, 1988; Basurco, 2000). The techniques are *close-to-INTAQ* in the sense that they are multi trophic with elements of biofiltration provided by endemic species present in the enclosure. The high nutrient level in the enclosures is sufficient for both carnivorous species such as sea bream and sea bass and for detritivores such as mullet. The level of intervention is, however much lower than INTAQ, artificial feed is not used and the primary

TABLE 2
Classification of INTAQ and similar cultivation systems by prevalence, location and cultured species

Technique	Prevalence	Location	Focal species	Co-culture species	Stage
Cage/floating structures	rare	Greece, Turkey, Israel, Croatia,	Seabream, Seabass,	Mullet, Sea Cucumber, Sponge, Mussel,	Experimental, pilot
Land-based pond/tank	rare	Greece, Turkey, Israel, Croatia,	Seabream, Seabass,	Mullet, Mussel, abalone shrimp, Seaweed (Ulva and Gracilaria)	Experimental, Pilot, commercial
Lagoon/marine enclosure/Valliculture/ estuary/other brackish water	Traditional/ Regional	Italy (Po River Delta)	Seabream, Seabass, mullet,	Eel	Commercial, Artisanal
Benthic harvesting,	unknown	Vicinity of monoculture installations	various	Various benthic organisms (not cultured but attracted by biofouling and harvested)	unknown
Artificial Reefs combined with monoculture	Very rare	Spain, France Italy	Seabream Mussels	various pelagic organisms (not cultured but attracted by structures and biofouling and harvested)	Experimental

objective is finfish harvesting, not joint production though a small amount of eel (200 tonnes per annum) is harvested.

Harvesting increased benthic and pelagic production

A second type of "unplanned" INTAQ results from "spillovers" from monoculture to the surrounding environment. Benthic enrichment from sedimentation is an unintended consequence or spillover from monoculture. The enrichment from sediments attracts finfish, crustaceans and other species to the areas around fish cages. Similar phenomena have been observed around open water structures (e.g. artificial reefs), even without sedimentation. The increased abundance of the wild organisms in proximity to existing operations makes them relatively easy to harvest (Dempster *et al*., 2002; 2004; 2005; Dempster and Taquet, 2004). As in the case of valliculture, there is a very low level of control over the movement/migration of different species, their growth and final biomass as compared to INTAQ. However these organisms are using discharges from fish farms to produce additional biomass, creating the potential for an additional marketable harvest as shown in other regions (Soto and Jara, 2007). In the Mediterranean Sea the extent of the activity (i.e. production levels and values) is unknown at this time because it is largely unregulated. Also a management issue that needs to be explored is "access". Generally, a license to operate a fish farm grants exclusive rights to an area to a single operator. Unless the farmer harvests the migrating wild stocks or explicitly permits a fisherman to do so, the activity could be construed as illegal. Evidence from other regions, such as Chile (Soto and Jara, 2007), points to the need for further exploration of potential for increased benthic and pelagic production and institutional means of encouraging harvesting and other beneficial practices associated with these increases (Cataudella, Massa and Crosetti, 2005).

A similar phenomenon has been observed with respect to corals growing in proximity to cage farms in the Red Sea near Eilat and early stage experimentation with artificial reefs in Israel, Spain, France and Italy. Angel *et al.* (2000a) and Bongiorni *et al.* (2003) found that corals flourish around fish farms. This observation sparked the establishment of a coral nursery adjacent to the Eilat fish farms for broken corals retrieved from the Eilat coral reserve (Shafir, Van Rijn, and Rinkevich, 2006). The idea is also being adopted in several other research projects that focus on reef restoration in Indo Pacific and other tropical regions. Artificial reefs located near finfish cages in Spain, France and Israel and near mussel lines in Italy have acted as fish attracting devices with the migrating organisms consuming detritus from the farms.

There is preliminary evidence that spillovers may also be regional. Machias *et al.* (2005) and Giannoulaki *et al*. (2005) observe that aggregate regional fish landings in the Mediterranean Sea are positively correlated with the expansion of aquaculture although caution must be taken in interpreting this correlation since causation has not been established. Though the increase in certain wild pelagic stocks may be a result of increased nutrient levels caused by aquaculture, it could also be the result of recovery resulting from conservation efforts and lower dependence on capture fisheries as supplies of cultured fish become more dominant in the market. Moreover, even if causation can be shown, caution must be exercised. This is because, on one hand, the increase in wild fish stocks has positive aspects, especially for the capture fishery and communities' dependent on it and possibly in terms of biodiversity. At the same time, it can be taken as evidence that current mariculture practice is altering aspects of the ecology of the Mediterranean Sea ecosystem in uncertain and potentially irreversible ways. Until more is known about the interactions between aquaculture and changes in the Benthic and Pelagic levels, the Precautionary Principle favors practices such as INTAQ because of their potentially lower and better managed environmental impacts.

Formal regulations, legislation and guidelines governing the environmental impacts of aquaculture and potentially of INTAQ

The current legislative and regulatory context for INTAQ in the Mediterranean Sea region is largely the same as for aquaculture in general. Regulation of aquaculture is relatively new, having lagged behind the large scale and rapid growth in the industry. INTAQ is not singled out as a subcategory of aquaculture because it is so new. This means that INTAQ is subject to the same mix of international, European, regional, national and local geographic jurisdictions and mandates including fisheries, environment and coastal zone and marine management as aquaculture. Because regulation of aquaculture is underdeveloped and does not contain provisions specific to INTAQ, this review focuses on existing frameworks and where possible, their implications for INTAQ and provisions needed to encourage the expansion of INTAQ. In many cases such provisions are also relevant to the industry as a whole, since regulation tends to be rather restrictive. That is, INTAQ stands to benefit from many policies aimed at encouraging aquaculture. The review below, demonstrates that there is a clear need for comprehensive and consistent policy frameworks at all levels. Equally important, though somewhat beyond the scope of this review is improving knowledge of existing provisions that either inhibit or encourage INTAQ and identifying those that need to be incorporated into new policy. Anecdotal evidence from Turkey and northern Europe, provide several examples. In parts of Turkey, fish farms have been ordered to relocate to offshore sites because of stakeholder conflicts, especially with the tourist industry and generally negative public perceptions. Given current farming techniques, offshore positions restrict many INTAQ options, especially those involving seaweed culture. In a number of countries in northern Europe, certain kinds of INTAQ are not possible because of restrictions requiring large distances between installations for finfish, bivalves and shellfish because of concerns for pathogen transfer. The types of issues that need to be examined include those above as well as whether integrated operations will be bound by more regulation that monoculture. For instance, would a finfish-mussel farm need to comply with separate provisions for each species or would it be treated as an integrated entity subject somewhat different rules?

We have reviewed the main regional and where possible national legislation and regulation at both the formal and informal levels. Because there is a great deal more material available than that presented here, detailed references are included for readers who are interested. There are a number of comprehensive reviews of legal, institutional and regulatory frameworks as well as forms of self-regulation by professional membership organizations such as the Federation of European Aquaculture Producers (FEAP, 2000). This review draws heavily on the following sources:

- National Aquaculture Legislation Overview (NALO) of the Fisheries and Aquaculture Department of the FAO www.fao.org/fi/website/FIRetrieveAction.do?dom=collection&xml=nalo.xml
- Monitoring and Regulation of Marine Aquaculture (MARAQUA) 1999-2001 Project: www.lifesciences.napier.ac.uk/maraqua/
- Federation of European Aquaculture Producers, www.feap.info/feap/

Within the Mediterranean Sea, aquaculture is governed according to a hierarchy, at the top of which is legislation and laws, following by regulations that enact and enforce the laws at the operational level and finally self-regulation under guidelines and codes of conduct and practice. Legislation and regulation bind the producer to actions at all stages, from the site selection, size, construction and operation of the fish farm. They are the product of the political process and may be international, regional or local in origin. Violation of legal obligations results in sanctions and other penalties when proper monitoring and enforcement mechanisms are in place. In contrast, self regulation (or informal regulation) is not mandatory. To be effective, it must be in the spirit of the existing legal context but adherence to codes of self regulation is facilitated more by demonstrated mutual benefits and a clear understanding of the consequences of participation and cooperation that accompany adoption of given voluntary codes. Many of the international agreements, conventions and other events listed in the Appendix are relevant and in this presentation, their specific application to the EEA is highlighted. Table 4, at the end of this section provides a summary of relevant formal and informal/soft types of regulation.

Formal legislation and regulation

Most international regulation relevant to the Mediterranean Sea is also at the global and European Union (EU) levels. There are a range of international agreements to which many Mediterranean Sea countries are signatories. The ones having the most direct input into national level policies affecting mariculture are: United Nations Convention on the Law of the Sea (UNCLOS, 1982) and associated agreements; Article 9 of the FAO, Code of Conduct for Responsible Fisheries (FAO, 1995); UN Biological Diversity Convention[6] and the World Heritage Convention.[7] At the European level, the Common Fisheries Policy and eight EC directives directly impact the practice of mariculture. These directives range from those governing specific aspect of environmental and resource quality to system management as a whole. In addition, there are over fifty other directives that indirectly pertain to mariculture. Currently, the movement towards integrated coastal zone management (ICZM) and the application of various systems approaches, in particular the Ecosystem Approach in the EU and worldwide are the dominant paradigm for mariculture policies (Read and Fernandes, 2003; Fernandes, Miller and Read, 2000). Most of the EU directives incorporate provisions for specific local condition within Environmental quality Objectives (EQO) and Environmental Quality Standards (EQS). These facilitate the formulation of national policies within the context of the EU directive. They also recognize the complex interactions between the various uses of coastal and marine resources and the need to protect aquatic environment in order to safeguard aquaculture in the face of other potentially polluting activities (Eleftheriou and Eleftheriou, 2001). Many non-EU-member Mediterranean Sea countries use these directives as the basis of national policy. Read *et al.* (2001) provides a comprehensive review of international and EU agreements and directives that affect mariculture. Although not INTAQ specific, these provisions will be the basis for facilitating the expansion of INTAQ as agreements and directives on mariculture change in order to keep pace with development in the industry.

Policies at the national level reflect the international and regional level. That is, few countries have special legislation on aquaculture, though several began drafting special sets of rules in the early 2000's. These include Bulgaria, Croatia, Cyprus, Malta and Morocco (Van Houte, 2001). In most countries aquaculture falls under the auspices of the Ministry of Agriculture or Fisheries and is further subject to a range of environmental, water, zoning and other regulations.[8] Environmental Impact Assessment (EIA) provisions are becoming more and more common as part of the licensing process. There is also a tacit recognition by some that aquaculture is primarily

[6] www.cbd.in

[7] www.whc.unesco.org/en/conventiontext/

[8] van Houtte (2001) notes that traditional government bureaucracies tend to be organized along one of the following:

- use-specific lines – i.e. separate administrations responsible for water supply, land allocation, seed supply, import/export etc.;
- functional lines – separate administrations for water resources allocation, pollution control, disease control, etc.;
- types of water resources - freshwater, brackish water and sea water; or
- land resources - public lands, shore, lagoons, private land management, etc.

Aquaculture crosses all of these lines because of its dependence on several resource systems.

a business enterprise and funding of enterprise support tools as well as improved information on authorization processes and operational guidelines has been undertaken by some governments. This process dovetails with the trend toward stakeholder processes and greater public participation in resource planning as both aquaculturalists and non-aquaculturalists have better access to the same information.

The specific provisions for enforcing legislation tend overwhelmingly toward physical regulation and command and control measures, with well-defined penalties for violations including revocation of licenses, imposition of fines and criminal prosecution. The design of these measures is meant to provide, in the first instance, deterrents to unauthorized, inappropriate or dangerous practices. If they fail as a deterrent, they are intended as punishment and a means of stopping the undesirable activity once it has begun in order to remediate environmental damage. As is the case at the executive/legislative level, implementation and enforcement of regulations is marked by overlapping authorities. In many African countries, including those with Mediterranean Sea shores, responsibility for aquaculture may be assigned to several ministries without any coordinating framework. In general the complicated regulation structure does not seem to facilitate the sustainability of aquaculture but the opposite and a wide implementation of INTAQ may require reviewing and adapting at least some parts of the existing regulations. The possibility of creating incentives for the implementation of INTAQ deserves careful review.

Self-regulation

In Europe, the Federation of European Aquaculture Producers (FEAP) is the main membership-based, self-regulating body. Since 2000, the FEAP Code of Conduct governing environmental quality has been in place (Hough, 2001). It has 28 signatories and covers:

- water use and quality
- abstraction and discharge
- site selection
- site management
- escapes
- therapeutic actions

National producer associations also exist. Table 3 gives a national review of the dominant national associations in the region.

Codes of practice generally detail guidelines for day to day operations of fish farms. They may be developed under formal regulation, codes of conduct or both. In the Mediterranean Sea, the last option is common in countries that have national plans for aquaculture. Greece is the first country to have had a national plan for aquaculture and Code of Practice to which 50 percent of producers adhere (Christofilogiannis, 2001). Other Mediterranean Sea countries with national aquaculture plans include Cyprus, Egypt, Israel, Turkey, Italy, Malta, Spain, France, Morocco and Tunisia. Codes and other voluntary guidelines are enforced by measures such as suspension of certification or of membership in professional bodies. As in the case of formal regulation, a thorough investigation of the codes is needed in order to identify their orientation with respect to INTAQ and to identify aspects that need to be incorporated in order to facilitate it.

Technological requirements and general investment range for a variety of systems

Commercial-scale INTAQ is rare in the Mediterranean Sea, but experimental, pilot and early commercial stage evidence, both from the Mediterranean Sea and elsewhere (west and east coasts of Canada; New Hampshire, United States of America; western Scotland and southern Chile), can provide the basis for inferences as to the technical

TABLE 3
Federations of aquaculture producers in the Mediterranean Sea (in 2001)

CROATIA (1) The Aquaculture Group **CYPRUS (3)** Cyprus Mariculture Association; CYFISH; Yalos **FRANCE (5)** FFA - Federation Francaise D'Aquaculture; Syndicat Francais des Aquaculture Marins; Syndicat des Selectioneurs Avicoles et Aquacoles Francais; Comite National de la Conchyliculture; Sections Regionales de la Conchyliculture **GREECE (12)** FGM - Federation of Greek Maricultures; Greek Aquaculture Producers Union; Fish Farmers Union of the Northern Aegean Sea; Fish Farmers of Dodecanese; Aquaculture Producers Association of Northern Greece; Panhellenic Confederation of Agricultural Cooperatives Unions; Fisheries Cooperative Chalastra; Fisheries Cooperative Eilikrineai; Fisheries Cooperative of Kymina-Malgara; Greek Mussel farmers- Mollusc farmers Association; Mussel farmers Association of Pieria Prefecture; Mollusc culture Cooperative of Makrygialos **TUNISIA(1)** Union Tunisienne de L'agriculture et de la PTA **ROMANIA (0)**	**MOROCCO (1)** Association Marocaine de l'Aquaculture **ITALY (1)** API - Associazione Piscicoltori Italiani **MALTA (1)** Malta Aquaculture Producers Association **SPAIN (2)** APROMAR - Asociacion Empresarial De Productores De Cultivos Marinos; OPAC - Orrganisacion De Productores De Acuicultura Continental **TURKEY (4)** Turkish Aegean Aquaculture Association; Bodrum Fisheries Society; Fisheries Society (SUDER); Turkish Fisheries Foundation (TURKSU) **ISRAEL (3)** Fish Breeders Association; Tnuva; Fish Breeders Organisation **EGYPT (7)** Damietta; Amryaa; Fayum; Sharkia; Al-Tyna Plain **BULGARIA (2)** Bulgarian Fishing Association (1998);Bulgarian Fish Producers Association

Source: FEAP* and Christofilogiannis (2001).

* www.feap.info/feap/

requirements for INTAQ systems in the Mediterranean Sea. The focus is on cage mariculture, rather than on-land, for two reasons. First, it is the most common form of mariculture in the Mediterranean Sea (Mathe *et al*., 2006) and therefore the most likely model for INTAQ to follow. Second, on-land INTAQ systems tend to be customized from the design stage, not adapted from existing operations and the range of design and engineering options for both joint production and effluent treatment is quite large (e.g.: polyculture ponds; monoculture ponds with water recirculation through various stages, etc.). Also, in the case of in-sea installations, the environmental issues are quite specific and the options for design are more limited, especially for effluent treatment. Therefore, the following discussion extends applications of temperate zone, cage INTAQ to the Mediterranean Sea, notwithstanding the fact that in some cases considerable adaptation will be required to implement such systems locally.

Considering technological requirements, the parameters for investment and operations vary considerable. On-land mono-culture installations are generally more expensive to construct and have lower returns on investment than do cage systems. For example, Lisac and Muir (2000) compared sea bream culture in 1 000–2 000 m^3 rearing volume concrete tanks with 2 500–3 500 m^3 rearing volume open sea cage systems. They found that investment requirements for the land-based systems were on average 1.5 times higher than the open sea systems and operating capital was 1.2 percent higher. The average internal rate of return (IRR) for land based systems was two percent, considerably lower than the 16 percent IRR for the sea cage systems. Recirculating land-based systems, in-particular may be quite expensive to construct and maintain. Pro-forma comparisons of the performance of INTAQ systems with monoculture finfish counterparts have shown that financially, the former have distinct advantages. Preliminary results from a case study based on an experiment of integrated sea bream – mullet cultivation in Israel (Angel and Freeman in prep.) show that for a range of assumptions, the INTAQ installation has distinct environmental

TABLE 4
Formal and self-regulation of environmental impacts of aquaculture

Jurisdiction	Detail	Sponsor, type (guideline, law, directive) and title
International	Provides a basic framework for comprehensive ocean governance.	United Nations Convention on the Law of the Sea (UNCLOS,1982) and associated agreements
International	Aquaculture Development and responsible aquaculture at production level *"9.1.1 States should establish, maintain and develop an appropriate legal and administrative framework which facilitates the development of responsible aquaculture."*	FAO; Code of conduct; Code of conduct for Responsible Fisheries (CCRF), Article 9
International	Of particular relevance, UNEP, 1998: Ecosystem approach under the Convention on Biological Diversity. Information Document No. 9 (UNEP/CBD/COP/4/Inf.9), 4th Conference of the Parties to the CBD to be held in Bratislava, Slovakia from 4 to 15 May 1998	1992 Biological Diversity Convention (1992); World Heritage Convention (1972).
International - EU	Primary policy framework for European fisheries sector	Common Fisheries Policy (CFP)
International - EU	EC directives are implemented at the national level by EU member states through national legislation and regulations and other restrictions.	Eight EC Directives directly governing environmental impacts of mariculture: • Dangerous Substances Directive • Quality of Shellfish Growing Waters Directive • Shellfish Directive • Environmental Impact Assessment (EIA) Directive • Strategic Environmental Assessment Directive (SEA) • Species and Habitats Directive • Wild Birds Directive • Water Framework Directive. More than fifty Directives, Decisions and Regulations indirectly affecting the monitoring and regulation of marine aquaculture (Read *et al.*, 2001).
Mediterranean Sea	Provides Best Available Technology (BAT) and Best Environmental Practice (BEP) designed to limit the pollution from fish farms in the Baltic Sea and in adjacent coastal areas where discharges enter the Baltic Sea.	Helsinki Convention (HELCOM) for the Protection of the Marine Environment of the Baltic Sea Area The Barcelona Convention for the Protection of the Mediterranean Sea against Pollution. General Fisheries Commission for the Mediterranean Sea
Professional Association	Strong self-regulation and enforcement by members through codes of practice, Management Schemes, Quality Schemes, and labelling and certification schemes	Federation of European Aquaculture Producers (FEAP); Voluntary Code of Conduct; FEAP Code of Conduct
Other	PARCOM Recommendation 94/6 on "Best Environmental Practice for the Reduction of Inputs of Potentially Toxic Chemicals from Aquaculture Use" is a benchmark for best practice beyond North East Atlantic	OSPAR; International Convention; Convention for the Protection of the Marine Environment of the North East Atlantic

and production/economic advantages over its sea bream monoculture counterpart. On the production side, the experimentation described in Porter *et al.* (1996), Katz *et al.* (2002) and Lupatsch, Katz and Angel (2003) showed that detritus from sea bream cages was sufficient to support mullet culture in enclosures beneath the sea bream cages. This contrasted with enclosures located 100 metres away from the cages, inside which the mullet could not survive solely on ambient nutrients. When the experimental production results were fed into an economic model, return to the investment and profits for the integrated farm was found to be on a par or slightly better than for monoculture as long as the price of sea bream was stable. The market price of mullet is much lower than that of sea bream and the level of production for this experiment was rather low. That is, the price of the primary species drives the profitability in this case.

The conclusions at this stage are that although the production benefits from integration were marginal, there is clear evidence that discharges into the environment can be lowered with no losses to the farmer and this speaks in favour of INTAQ. Moreover, this experimental evidence clearly indicates that with more intensive culture of the secondary species and in particular, the choice of more profitable species the overall production and economic benefits could be much larger.

The "classic" coastal INTAQ system could consist of a net cage or net pen fish farm and shellfish (usually mussels) and/or macroalgae (usually kelp). In practically all cases fish farms are designed as "monoculture" farms where all gear and moorings serve the fish cages/pens.[9] INTAQ components are usually added on afterwards in an attempt to reduce ecological effects and to increase and/or diversify aquaculture production without adding manufactured pellet fish feed (the most costly operating input) provided to the system. In such cases, baskets with shellfish and/or longlines with shellfish and/or macroalgae are either moored separately (as in Figure 1) or are attached to the existing fish farm mooring lines and structures.

However, a well-planned fish farm will consider features such as bathymetry, prevailing wave and wind and current directions and intensities to minimize risk of damage to the structures and to the health of the fish stocks. It is likely that the addition of INTAQ components to the system will affect aspects such as the structural integrity of the farm, circulation and water quality inside the net pens. Also the best design to obtain the highest benefits from the INTAQ production requires effective planning therefore this is highly recommended at the design and engineering stages. This needs to be done together with simulations of the effect of variable physical conditions on the integrity of the farm structures and to modeling of the effects of the INTAQ system on water quality inside and around the farm. It has been shown that an action as simple as rotating (swiveling) the orientation of aquaculture cages or shellfish longlines relative to the direction of the prevailing current can dramatically improve water circulation and quality inside the cages (Richardson, 2003; Newell and Richardson, 2004). Moreover, redistribution or aggregation of the INTAQ components relative to the fish cages or to one another may also improve water flow (and thereby water quality) through the cages. Ultimately a comparison of the performance of these various options will determine whether the INTAQ option is viable.

A variation on the classic scheme has been proposed by Cross (2004) in western Canada. His design incorporates shellfish and seaweeds within the farm rather than at the perimeter of the farm. By integrating the shellfish components within the physical structure of the finfish net pen farm, rather than on the outside, there is considerable reduction in moorings and other infrastructure required to stabilize the system. Moreover, by proper planning and timing of shellfish and finfish stocking, maintenance, handling and harvesting of each of the cultivated stocks may be done more efficiently by a small team at the farm.

In addition to the considerations for coastal mariculture, mention needs to be made of technical requirements for offshore or deepwater mariculture. One of the challenges that faces both monoculture and integrated aquaculture farmers is the growing acceptance that further expansion of coastal aquaculture is limited by physical space constraints and the ever increasing pressure by multiple stakeholders on the already overloaded coastal zone. Already, some Mediterranean Sea monoculture farms are choosing to move to offshore locations. One of the main challenges posed by open ocean aquaculture is the economic feasibility of the operation considering added expenses involved in such aspects as deep water mooring, special structures that can withstand open ocean conditions, travel costs from shore to the farm site for daily maintenance, harvesting, etc. Because the INTAQ components have requirements

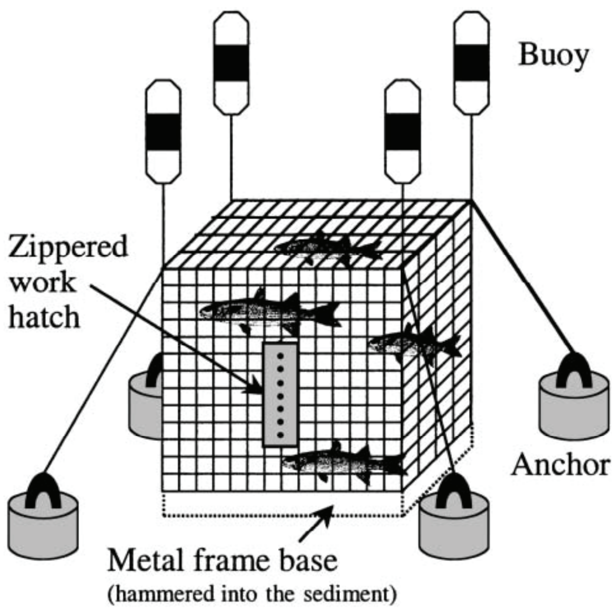
[9] Beveridge (1996) provides a very good reference for design and construction specifications.

that are not identical to those of the finfish, transition to an open ocean site may require special engineering solutions and, potentially, added costs to the farm that may detract from the joint-production benefits of co-cultivation. Another important consideration is the environmental benefits of reduced effluent from INTAQ practices. These are probably highest in the coastal areas where pollution levels are highest because of lower water circulation and congestion. Therefore, there is a strong case to be made for encouraging INTAQ in coastal areas as an alternative to monoculture. Given the prevailing negative attitudes towards aquaculture, information, information dissemination and public education will be critical components in the process of improving acceptance of INTAQ practices.

A variety of INTAQ systems have been considered to enhance the sustainability of finfish aquaculture in the Red Sea and the eastern Mediterranean Sea and a few of these will be briefly described below.

Seabream – mullet INTAQ. In the series of experimental-scale trials mentioned in the Israel country overview, Porter *et al.* (1996), Katz *et al.* (2002) and Lupatsch, Katz and Angel (2003) found that grey mullets placed in benthic enclosures (that were open to the underlying sediments) below a commercial sea bream/sea bass fish farm effectively removed organic carbon, nitrogen and phosphorus from the organically enriched sediments and grew at a rate equivalent to that of mullets reared in brackish water ponds on land. Scaling up such INTAQ systems to a pilot or commercial scale operation would involve construction of large bottom enclosures for deployment of mullets or other detritivore fishes (or invertebrates) using systems similar to those used for rearing of such bottom-feeding flatfishes as sole and flounder.

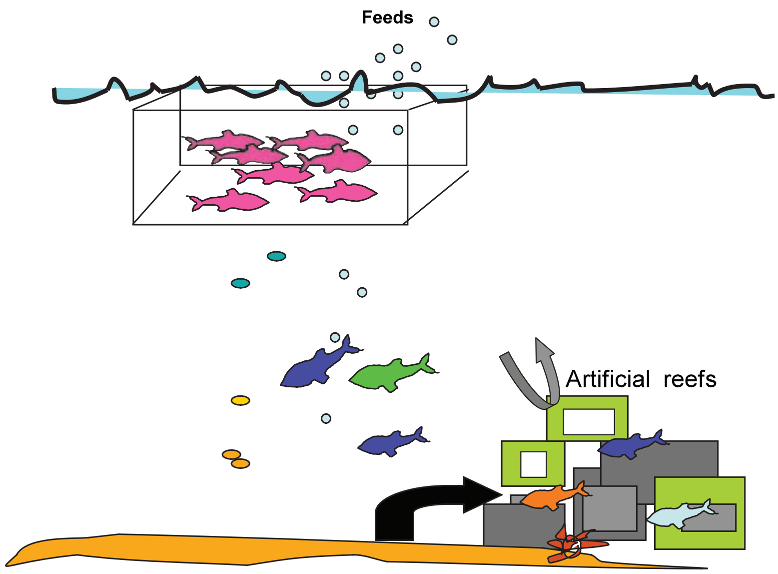
FIGURE 6
Sketch of a 1 m^3 (1 m width, 1 m height) benthic enclosure stocked with mullets



Source: Katz, *et al.* (2002).

Seabream – artificial reefs. Artificial structures placed around and/or below commercial fish farms serve as substrates for the development of natural fouling communities which may absorb some of the fish farm effluents, thereby enhancing the sustainability of the farms. We have observed that such structures may provide benefits that are similar to the more traditional INTAQ systems. Specifically, they may have the environmental benefits required by INTAQ, but the production/economic benefits accrue to a wider public than in the case of a fully integrated farm or several farms working in conjunction with each other. As a result, there are a number of property rights issues that influence incentive for the development of artificial reef systems; these include the rights to harvest migrating organisms and other activities in the vicinity of the reefs. The underwater structures boost local biodiversity as they attract benthic, demersal and pelagic fishes and invertebrates (Angel *et al.*, 2002) which trap and absorb particles released from the fish cages (Lojen *et al.*, 2005) thereby reducing impacts on the surrounding ecosystem (Figure 7). In addition to increasing biodiversity in the vicinity of the fish farms, the communities that develop on the artificial structures may serve as underwater attractions for tourism. The designs of the underwater artificial structures may be extremely diverse in terms of material, shape, etc. Several small scale deployments have been tested next to fish farms in the Red Sea, in Hong Kong and in Spain but none of these have been scaled up to larger structures. Although such systems show promise, there is a need for further research on issues such as size of structures, depth of deployment, orientation relative to the fish cages, optimal materials, effectiveness of biofiltration and economic feasibility.

FIGURE 7
Schematic for an artificial reef adjacent to fish cages



Environmental considerations

We consider the environmental impacts of INTAQ from two perspectives. The first is the overall environmental context of the Mediterranean Sea region and environmental issues of primary concern in the region. The issues are relevant to the aquaculture sector as a whole, not just INTAQ. Since public perceptions about aquaculture and regulatory attitudes towards it are often heavily influenced by these environmental concerns, they are relevant when considering the potential for expanding any aquaculture practice, including INTAQ. The second perspective is comparative, examining the potential environmental benefits of INTAQ over monoculture. The comparison and assessment relies on the perspective of the ecosystem approach and uses the conceptual tools discussed in the Introduction as a frame. When possible, quantitative measures are provided. Because INTAQ is so rare in the Mediterranean Sea region much of our data has come from the aquaculture sector in general (Soto and Crosetti, 2005), experimental results and evidence from non-Mediterranean Sea experience with INTAQ.

The Mediterranean Sea environment and environmental concerns: overview

EEA (2006) lists the following as the main issues of environmental concern:

- sewage and urban run-off
- solid waste
- industrial effluent
- urbanization
- eutrophication
- sand erosion
- marine transport
- biological invasions
- harmful algal blooms (HABs)
- exploitation of marine resources
- expansion of aquaculture
- natural hazards

This rather long list highlights not only the range of stressors affecting the Mediterranean Sea ecosystem, but also previews potential stakeholder conflicts and environmental challenges facing aquaculture and the opportunities for the expansion of INTAQ. Significantly for INTAQ, the expansion of aquaculture was highlighted as one of five emerging environmental threats in two major reports (EEA, 1999; 2002). This is extremely important for INTAQ. First, it reveals the extent to which negative attitudes towards aquaculture prevail. If these attitudes dominate policy decision-making, then the expansion of the industry, including INTAQ could be difficult. At the same time, INTAQ's environmental advantages directly answer some of the concerns about aquaculture and this may be an important opportunity. If INTAQ is shown to be more sustainable than monoculture, then it could become the leading edge for practices promoted by industry and policy makers. In addition, mariculture, including INTAQ has been a partial solution to the problem of stressed wild fish stocks, reductions in landings and increased consumer demand for marine products. It also has been instrumental the creation or maintenance of jobs and other economic opportunities in places traditionally dependent on capture fisheries. Therefore, in the wider context of the ecosystem, that includes ecological systems, fish resources and human communities, INTAQ could well be part of a sustainable solution (EEA, 2006; Jensen, 2001; Commission of the European Communities, 2002).

Environment and public image: potential benefits of INTAQ over monoculture

Rapid expansion is the defining characteristic of the mariculture sector in the Mediterranean Sea. In 2005, it produced nearly twenty times the tonnage that was produced in 1970 (375 560 tonnes vs. 19 997 tonnes), with most of the increase taking place after 1988 (EEA, 2006). Based on Fischler's (1999) estimate and given the sector's growth, aquaculture employs more than 70 000 people. It also has attracted considerable negative attention. Aquaculture's poor public image is in part due to observed adverse environmental impacts. During the period of rapid growth, farms proliferated and there were instances of poor management and accidents. Issues such as pollution, contamination of wild stocks from disease or fish escaping from cages and depletion of wild stocks for the production of manufactured feed and capture of fry have attracted widespread public attention and contributed to the poor image (Black, 2001; Basurco, 2000; Gowen and Bradbury, 1987; Hargrave, 2005; Heinig, 2001; ICES, 2005; Mazur, Aslin and Byron, 2005; Tlusty *et al.*, 2001; Naylor *et al.*, 2001). Often, the public's introduction to aquaculture is in the form of very negative media reports and in the absence of other information, negative opinions are formed. Thus, a second contributing factor to the image of aquaculture is the lack of knowledge and a degree of uncertainty. The process of developing understanding and creating an information base is ongoing and will take time to develop. A third important factor in the formation of public opinion is the fact that often, aquaculture installations compete with other stakeholder activities in the coastal zone. This will not change as the zone has multiple legitimate uses and an important part of policy is equitable and efficient allocation. Thus the image of aquaculture and public attitudes toward it can be influenced by good information and public education but also by policy development processes that accommodate various stakeholders, local, national and regional priorities.

Ecological effects at the farm level have received the most study but it has been difficult to generalize them or extrapolate the results up to the ecosystem level because of multiple and complex interactions between the farm and its larger environment. Even at the farm level, it has been difficult to determine standards for acceptable and unacceptable impacts in terms of degree and spatial extent (Heinig, 2001). Another issue in the Mediterranean Sea context is that much of the research has been conducted outside the region and may or may not be applicable. The fact that there is perceived impact and that conflicts exist is sufficient cause for a closer examination of the impact of aquaculture on the human and physical environment. (GESAMP, 1991; UNEP/MAP/MEDPOL, 2004).

Given the relatively short history of large-scale commercial aquaculture in the Mediterranean Sea, its integration in multiple management systems (e.g. fisheries, coastal zone, environment, marine resources, etc.) and the newness of system approaches applied to environmental/ecosystem management, it is not surprising that comprehensive ecosystem models of aquaculture are unavailable. Nevertheless, heuristic observation is possible and offers important indications for continued research. Referring to the list of main environmental concerns in the previous sections, all four carrying capacities are evident. Public image and competition among stakeholders in the coastal zone are clearly within the realm of social *carrying capacity*. Moreover, the better public image potential for INTAQ means that *its social carrying capacity* may be higher than that of monoculture. The specialized technical specification of integrated farms may limit the *productive carrying capacity* of open water sites for INTAQ while the integration of multiple species should increase the *productive carrying* capacity of more sheltered coastal sites. The lower effluent inherent in INTAQ poses less of a challenge to *ecological carrying capacities* and this may provide a wider scope for site selection, including areas that might otherwise be too sensitive to accommodate monoculture, resilient enough for INTAQ. In each of these examples, the importance of the *physical carrying capacity* is evident. For instance currents determine both the rates at which sediment is dispersed and the technical requirements of the farm. Water temperature determines growth rates of cultured organisms and absorption of effluent within the farm's zones of influence and the extent to which a particular site stands to benefit from INTAQ.

Table 5 summarizes the main ecological spillovers for which INTAQ practices may offer improvements in the Mediterranean Sea. The list in the table is a subset of aquaculture related issues raised by many research and policy bodies. The following section provides a detailed discussion of the potential improvements from an ecological standpoint.

Farm effluent and changes in diversity: comparing monoculture and INTAQ

While theoretical, experimental and pilot level evidence points to INTAQ as a lower emission process than monoculture, an optimal analysis of the environmental benefits of INTAQ requires at the very least, accurate data on the:

- uptake of dissolved and particulate matter by seaweed and detritivore species;
- amount that the uptake represents (in absolute and percentage terms) of baseline effluent from the monoculture counterpart;
- difference in terms of primary ecological impacts caused by the changes in effluent levels (dose-response differentials).

TABLE 5
Ecological spillover: comparing monoculture and INTAQ

	Monoculture	INTAQ	
		IMTA (3 trophic taxa)	artificial reefs + finfish cages
Effluent I – uneaten food and detritus causes particulate accumulation in the water column (nutrification/ Eutrophication/turbidity of water column) and sedimentation	**High**	**Medium** Most uneaten food waste is contained within the system but faeces and excretory waste is discharged	Probably **Medium** but needs further study Discharge from cages is as for monoculture BUT an unknown portion is taken up by migrating species
Effluent II – excretory waste causes accumulation of dissolved nitrogen and phosphorous in the water column	**High**	**None** Wastes in solution absorbed by macro algae	**As above**
Effluent III – pharmaceutical and chemical contamination of water and sediments	**Low-Medium**	**Medium** May be higher than for monoculture if there is a risk of pathogen transfer between cultured species	**As for monoculture**
Ecosystem health – changes in diversity and risk; e.g. migration of wild detritivore species to vicinity of cages a secondary effect of sedimentation (Effluent I)	**High**	**Low**	**As for monoculture** but impact may be mitigated by harvesting

Main Sources: EEA, 2006; FAO, 2007; GESAMP, 2001; 1997; 1996.

Partial information on the first two items above is available both in the Mediterranean Sea and other regions. Little if any of the dose-response time data exists. In addition, there are wide variations over different co-cultured species and from region to region in levels of effluent, uptake and primary, secondary and tertiary impacts. For example, Angel *et al.* (1992) found that organic matter decomposition rate in sediments under fish cages in the Red Sea may be greater than in temperate climates by as much as a factor of four. Moreover, ICES (2005) cites evidence that proper physical farm structures and operating practices can greatly reduce effluent, leaving open the possibility that the engineering and design of systems will be at least as important as the choice and integration of species.

Filter feeding invertebrates, especially mussels, have been used to take up particulate organic effluents from fish farms whereas dissolved inorganic nutrients are preferentially absorbed by macroalgae. The authors of the various studies report nutrient uptake dynamics using a variety of different flux rates. This is a challenge for comparing results; nevertheless, the results provide an estimate of the potential for the mitigation of environmental impacts. In one of the few figures published regarding net pen INTAQ, the AquaNet project has shown that mussels and other filter feeders may remove as much as 20 percent of the particulate effluents released by salmon, equivalent to around 240 kg particulate C per day for a 1 000 ton farm at peak production (AquaNet Project)[10]. In the same study, it was estimated that a kelp cultivation system mounted on long-lines adjacent to the salmon farm could assimilate at least one third of the dissolved nitrogen load (mostly ammonia) released by the caged fish, equivalent to around 150 kg dissolved nitrogen per day for a 1 000 ton farm at peak production. Most of the quantitative studies of INTAQ systems were land-based experimental recirculation units which suggest that inorganic N and P recovery of dissolved fish effluents may range from 35 percent to 100 percent (Troell *et al.*, 2003). In experiments using juvenile salmon and freshwater mussels, phosphorous and chlorophyll concentrations in tanks were reduced by orders of magnitude of one and two compared to tanks containing only salmon. The presence of bivalves effectively

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converted a hypereutrophic environment to an oligotrophic one (Soto and Mena, 1999). In order to predict the benefit to the environment from reduced particulate effluents following integration of mussels with salmon in British Columbia (Canada), Cross (unpublished) used the particle tracking model DEPOMOD (Cromey, Nickell and Black, 2002) to compare the footprint of an INTAQ salmon farm to a monoculture farm and found an order of magnitude reduction in organically-enriched sediments (ICES, 2005). Soto and Jara (2007), studying both marine and freshwater salmon farming INTAQ-type approaches, note that in addition to direct uptake of nutrients by wild bivalves, the bioturbation produced by these moving mollusks reduced the impact of nutrient accumulation in the sediments underneath fish cages.

In addition to the environmental benefit of mopping up effluents, proponents of the "integrated" approach point out the economic benefits and advantages of INTAQ over monoculture. It is noteworthy that some studies show no significant differences in mussel growth rates when comparing between a deployment near commercial fish farms vs. reference sites, but these are generally the result of poor choice of shellfish deployment station since the deposit feeders must be close enough to the particulate effluent load in order to absorb and remove it. When properly sited, workers in the AquaNet project have reported increased growth rates of both mussels and kelp by as much as 50 percent over the growth rates of these biofiltering organisms at nearby reference sites (ICES, 2005). A rare Mediterranean Sea example is that provided by Peharda *et al.* (2007) in the Eastern Adriatic Sea. They find mussels' growth in a suboptimal area adjacent to aquaculture cages was as good as mussels grown in isolation in areas considered to be more suited to mussel culture. This example highlights the need for more geographically focuses study. Parts of the Adriatic have the highest level of primary production in the Mediterranean Sea region. For this reason, they are suited to monoculture mussel production and could also be well suited to forms of INTAQ.

In considering the scale of improvement the effect of aquaculture on sediments is much easier to measure and monitor than the effect of aquaculture on water column properties, such as dissolved nitrogen or phosphorous concentrations. Particulate matter falls to the seafloor below the net cages forming a benthic footprint, whereas dissolved compounds released from fish farms are dispersed by water motion and rapidly assimilated by micro and macroalgae in the water column making them more elusive. Moreover, suspended solids and dissolved effluents released from fish farms may have "far-field" effects (Milligan and Law, 2005) that are not detected within close proximity to the farms. As a result, sediments have been monitored more closely and benthic impacts have been copiously described and identified as a local problem. Particulate organic matter, mainly faeces and uneaten feed, settles underneath fish cages leading to high sediment oxygen demand and eventually anoxia (Black, 2001). The benthic effects are localized and the severity depends on a large number of factors that determine the organic matter decomposition rate and the extent to which deposits from the farms are dispersed, including bathymetry of underlying seafloor, hydrodynamics, nature of the sediment particles, water depth, temperature, etc. (Beveridge, 1996; Black, 2001). Organic matter accumulations are problematic because they can lead to changes in benthic flora and fauna (EEA, 2006) and may lead to loss of certain ecosystem services. Dispersal, while it may seem to be a solution to the immediate area around the farm may have implications for water quality (e.g. turbidity and oxygen levels) on a larger scale, with negative or potentially positive consequences (e.g. if enhancing production of wild organisms). This is an important consideration for areas that currently have many farms and for the future as the number of farms increases.

One of the observed consequences of organic enrichment has been the migration (attraction) of wild fish and invertebrates from surrounding areas to the proximity of the farms (McDougall and Black, 1999; Angel *et al.* 2002; Eden, Katz and Angel, 2003), thereby changing local diversity. INTAQ combines pellet fed species with invertebrate scavengers and plant biofilters, mimicking the natural fouling community observed around monoculture farms. By limiting the dispersal of particulate and dissolved effluents to the area close to the farm, environmental impacts on the surrounding area are reduced and agencies such as the Scottish Environmental Protection Agency have developed the concept of *Allowable Zone of Effect* (AZE) to regulate the spatial extent of such local impacts (SEPA, 2004; PROFET Policy, 2001).

With respect to diversity, the concern is that, at least locally, discharges from monoculture aquaculture cause an undesired or uncertain change. This has been amply documented with respect to macrofauna and meiofauna (Weston, 1990; Angel *et al.*, 2000b; Hargrave, 2005). The Pearson and Rosenberg model of macrofauna succession with respect to organic enrichment (Pearson and Rosenberg, 1978) is a widely accepted dogma regarding benthic impacts of mariculture (Black, 2001; Hargrave, 2005) which predicts a sharp drop in biodiversity with increasing organic enrichment. EEA (2006) cites mortality of benthic fauna, deterioration of sea grass meadows and changes in the trophic status resulting from aquaculture impacts. A well known case is that of the *Posidonia oceanica* sea grass meadows. These sea grasses are important habitat and food sources for a range of invertebrates, fish and birds as well as a buffer against coastal erosion and concerns about aquaculture impacts on them are the most frequently cited (Soto and Crosetti, 2005). In Fornells Bay, Menorca they were totally eliminated in areas around fish farms (Cancemi, De Falco and Pergent, 2000). Though they recovered following cessation of aquaculture, it took at least three years before any recovery became apparent (Delgado *et al*., 1999). In the case of overall ecosystem function, EEA (2006) conclude that monoculture, probably has detrimental impacts but the evidence is somewhat mixed and further studies are required.

Ecosystem issues common to monoculture and INTAQ

The previous section focused on production and environmental improvements offered by INTAQ. These are significant improvement from an ecological standpoint and should contribute to improved public perceptions and regulatory provisions that could facilitate the expansion of INTAQ. There are, however a number of other concerns that INTAQ shares with monoculture and though we do not discuss them in detail in this report, we do list them briefly in Box 2, because they are also significant and must be addressed in any aquaculture forum, including INTAQ. The list includes both potential negative spillovers from aquaculture to the environment and the effects of the surrounding environment on aquaculture operations. It also includes potential benefits of aquaculture as a whole.

Geographical areas and coastal zones most commonly used: where is INTAQ most likely to occur?

The expansion of INTAQ will depend on a combination of ecological factors, the current state of development of aquaculture in different places and the policy environment. In the near to medium term INTAQ is most likely to occur or expand in places where it already operates on experimental, pilot or commercial levels. Countries that already have a well developed mariculture industry with the physical and regulatory infrastructure, market support mechanisms and human capital that it entails will be the leaders. Greece, Turkey, Italy, Spain and Israel can therefore be expected to be early leaders in the expansion of INTAQ. They have the requisite infrastructure, financial, research and development base. In the longer term, follower countries will be those who have smaller industrial scale mariculture and who stand to benefit from adopting more mature INTAQ technologies, rather than developing them. Most countries in the southern Mediterranean Sea will fall into this category, with the possible exception of Egypt and Morocco which have relatively well developed aquaculture sectors. The benefits they stand to gain from the adoption of INTAQ are in the area of food

BOX 2

Main impacts and interactions relevant to Mediterranean Sea mariculture practice

Potential negative spillovers from aquaculture to the environment

1. **Impact on wild stocks I** – transfer of parasites and diseases
2. **Impact on wild stocks II** – escaped fish
3. **Impact on wild stocks III** – fry capture from wild stocks
4. **Impact on birds and marine mammals**
5. **Food safety**
6. **Stakeholder conflicts I** – farm sites inhibit other uses (e.g. tourism and recreation in the vicinity of farms)
7. **Stakeholder conflicts II** – spillovers among coexisting uses (pollution and hazards)

Effect of surrounding environment on aquaculture

1. **Effluent IV** – point and non-point source pollution from other users (e.g. sewage, industrial pollution, agricultural runoff, accidental spills)
2. **Stakeholder conflict I** – siting of the farm inhibited by other uses (e.g. existing urban and industrial installations may require off-coast sitings of farms.)
3. **Stakeholder conflict II** – e.g. risk to deep water farms from shipping and capture fisheries vessels
4. **Weather** – mainly the impact of severe weather on installations
5. **Wild animals** – usually cause damage to pens and cages; may involve predation
6. **Poaching**

Potentially positive impacts of aquaculture

1. **Business** (decreased cost, increased production)
2. **Employment maintenance and creation**
3. **Community integrity** in places dependent on fisheries (e.g. communities dependent on fish processing, transport, marketing, etc.)
4. **Creation of new economic opportunities** (e.g. hatcheries, non-conventional markets)
5. **Food Security** (maintaining sources of sea products in the face of stressed wild fish stocks)
6. **Improved management of fishery resources (**e.g. potential for aquaculture to relieve pressure on stressed wild fish stock)

Main Sources: EEA, 2006; FAO, 2005; GESAMP, 2001; 1997; 1996; Andersen, 2002.

security with lower environmental impact than monoculture. If INTAQ proves to be cost effective, then it may be the first stage of significant mariculture development in these countries, not so much replacing monoculture, but bypassing it entirely. Key issues of concern for these countries will be the cost of installations, training and other elements of developing human capital and property rights (Poynton, 2006; Ahmed, 2004). However INTAQ could be much more helpful and successful in countries and regions with fewer economic resources it is amenable to a variety of level of technological sophistication. If well guided and planned, it could provide benefits for a wide array of people of different social and economic levels. For example, the potential for setting mussel lines close to existing fish farms should be investigated, since mussel farming does not require complicated technology or expensive gear. Peharda *et al.* (2007) provide good evidence for the potential of such practices.

Places in which close-to-INTAQ production already takes place may also be locations in which practices can be formalized and expanded to fully realize the potential of integration. Instances of polyculture or collectivities of farms culturing different trophic species in close proximity are candidates. For example, in Olbia, Italy, there has been a rapid growth in finfish and mussel farms. The bay depicted in Figure 8 had virtually no aquaculture in 2005. Within two years, it was full of finfish cages and mussel lines.

From the standpoint of the social carrying capacity, areas in which INTAQ may be encouraged or adopted include offshore and more remote areas where competition for space is less intense than most coastlines. New offshore installations will have engineering requirements that will allow them to withstand rougher physical conditions in open water but will probably face less opposition from other stakeholders. Similarly, social acceptability of coastal aquaculture may be higher if the environmental advantages of INTAQ are understood and this may be another route to expanding the practice, notwithstanding congestion in the coastal zone. Moreover, rural support and development programmes in the entire region may benefit from INTAQ because of its environmental advantages and potential for business development and job creation in localities experiencing net outflows of population.

Since low primary production in many parts of the Mediterranean Sea has been cited as a constraint for INTAQ practices, we can also expect to see higher prevalence in the western basin and in areas such as the eastern and northern Adriatic Sea. Certain types of culture have specific nutritional or physical requirements, so from the standpoint of productive carrying capacities, consideration must be given to the feasibility of macroalgae and certain species of shellfish and their co-culture. Y. Karakassis (pers. comm.) points to ecological limitations affecting INTAQ in Greece where finfish and shellfish cultivation are physically separate. Specifically, the oligotrophic status of the water in the vicinity of many finfish farms in the eastern Mediterranean Sea is a limiting factor for introducing filter feeders to finfish cage environments as the low concentration of phytoplankton and detritus is probably insufficient for prolific mussel or other shellfish cultivation. The balance between low nutrient levels (specifically phosphates and ammonia) and low turbidity/high light penetration (Soto and Crosetti, 2005) may be the key to successful macroalgae co-cultivation. The former is a constraint while the latter may actually favour cultivation at depths not possible in other more nutrient rich ecosystems. Seaweeds also require a large area of fairly calm waters, characteristic of

FIGURE 8
Finfish cages and mussel farms in Olbia, Sardinia

inshore and land-based installations as turbulent physical conditions may cause algae to break off of the artificial supports near the fish cages used to cultivate these plants. The large areas needed may however be difficult to find in inshore waters.

Information requirements for better understanding of current practices and realization of major opportunities

INTAQ in the Mediterranean Sea is in its infancy and as such information on the practice, its consequences and potential is at a premium. At present, none of the major stakeholders and decision-makers, farmers, industry, lawmakers or the public at large have enough up-to-date, accurate information to fully understand the potential of INTAQ. The baseline characteristics of the physical and ecological carrying capacities of the region are reasonably well understood and the environmental concerns detailed in numerous reports give clear indications of the social carrying capacity. There is much less information on the productive carrying capacity for INTAQ. Some information on non-Mediterranean Sea experience, mainly from advanced experimental and pilot projects, can provide guidance, especially on the requirements for engineering, up-front investment and profit potential. To a lesser extent, these can also provide relevant information on the primary ecological impacts of INTAQ, for example, the potential nutrient uptake by detritivores and macro-algae. Specific information on the oligotrophic properties of the Mediterranean Sea and the challenges and opportunities it poses for INTAQ is probably the most critical gap that exists. We simply do not know what the implications are because there is so little experience. Another important gap is on the potential for new negative spillovers from INTAQ, for example, the transfer of disease among co-cultured species. Again more practical experience will contribute to fill such information gaps.

In addition to the creation of information, dissemination and outreach is also a key factor in determining the potential for INTAQ. This means that channels for transferring information from generators to users is important. In particular, education as a means of informing the public at large and influencing decision-makers will be an important element in promoting the social acceptability of INTAQ.

Finally, at the enterprise and market level, not enough is known about the production risks of INTAQ compared with other practices. Ridler *et al.* (2007) notes that the diversification of production may lower both production and market risk. For example, by cultivating two or more species, farmers could be exposed to less risk if the economic return one crop is compromised either by production failure (e.g. due to disease) or by significant drop in price. Only time and experience will provide information on these variables.

General evaluation of the major opportunities and constraints for INTAQ

As the preceding discussions indicate, INTAQ is potentially attractive in terms of both production and profitability and environmental sustainability. Nevertheless, very little of the practice is seen globally in marine and coastal environments. This is especially true of the Mediterranean Sea basin. Thus the focus of this section is the question: Why, given its apparent advantages has INTAQ not been adopted on a larger scale? In answering the question, we focus on two factors:

- the perspective of the operator given their awareness of the potential of INTAQ and expectations of returns on investment in INTAQ; and
- factors external to the operator that enhance or constrain the adoption of INTAQ.

Ridler *et al.* (2006) note that unless they are profitable, in the long run, INTAQ practices will not be adopted by farmers. It's expansion offers potential opportunities in three areas: (1) increased profitability at the farm level as a result of reduced feed and maintenance cost and increased production; (2) upstream diversification into non-traditional products (Chopin *et al.*, 2004) and reduction of market risk; (3) downstream business and employment opportunities such as the development of hatcheries and maintenance of existing processing, transport and marketing activities. The first two are of most interest to operators and the third to other businesses and local and regional planners concerned with communities that rely on the sector.

In assessing the profit potential of INTAQ, operators will need to be convinced, not only of its baseline potential in comparison to monoculture but also its potential in the face of existing and expected regulatory restrictions and other incentive instruments (e.g. taxes and subsidies, direct regulation, public image and consumer acceptance, etc.). For example, monoculture farmers are increasingly being required to pay for the environmental damage caused by their farms. This may be in the form of fines or installation of costly measures to prevent or treat effluent. In other cases, licensing may become more difficult for certain "undesirable" culture techniques or farms in certain areas. The Turkish fish farmers forced to move offshore because of the perceived impacts in the coastal zone and potential damage to tourism industry is a good example. Stricter regulation and enforcement of the practice of aquaculture may in fact be a source of opportunity for INTAQ if, because it is more acceptable, it becomes easier to license and/or less expensive to operate when the costs of regulation are added in to the profit calculation. Still, if farmers believe that changes in regulation such as in Turkey, will compromise their business, they will be less likely to risk the increased up-front investment required in setting up INTAQ operations.

INTAQ, as a new, untried technology presents both upside and downside risks, many of which will be resolved if enough experience is accumulated. For example, the risks to monoculture aquaculture over large periods with declining prices, such as those of 2001–2002, are well known (University of Stirling, 2004). The potential of diversified production to hedge against these risks is a potential incentive for the adoption of INTAQ but must be weighed against other negative productive carrying capacity risks such as unknown but possibly increased incidence of production losses due to cross-species contamination as a result of proximity.

In terms of factors external to the operator, most are in the realm of political and social acceptability and priorities of decision-makers. If the relevant stakeholders are convinced of INTAQ's advantages, there is a higher likelihood that it will be promoted both locally and regionally. The two advantages that are key in facilitating this promotion are in INTAQ's environmental sustainability and its potential for enhancing economic viability of farms and communities. The first has been discussed in considerable detail in the sections above. The second is reviewed here.

If INTAQ proves to be a viable means enhancing local economic activity, then rural communities in general and developing countries in particular, stand to benefit from more sustainable sources of enterprise, job creation and food security. Many Mediterranean Sea fishing communities are rural. In the absence of job opportunities, young people increasingly leave and communities are threatened. The experience in fishing areas in the north of Scotland points to the potential for INTAQ to help maintain their Mediterranean Sea counterparts. In Scotland, the development of aquaculture has been responsible for job creation and invigoration of local businesses in several communities under stress due to the decline in the capture fisheries. Jobs in the farms and local processing plants have reversed an outflow of young people from their communities (Commission of the European Communities, 2002). Similar opportunities have been observed in small Island communities in the Mediterranean Sea region. In these locations, there may be added advantages of food security, self-sufficiency, less competition and environmental pressure from industrial and urban sources than on mainland coastlines (Paquotte and Lacroix, 1997). A variety of incentive systems are needed to encourage the adoption of INTAQ practices in order to obtain benefits of these sorts. These include government support for small businesses, subsidies for new INTAQ farms and provisions to encourage collaboration among growers and harvesters of different species; for example, permitting mussel and finfish farms to locate in close proximity to one another and establishing legal frameworks that would permit more benthic harvesting.

Food security and the potential of INTAQ to contribute to economic development is a particularly important consideration for the southern Mediterranean Sea. Developing countries, mostly in Pacific Asia now supply most of the world's farmed fish. Aquaculture output is an important supply of animal protein for domestic consumption in these countries and a major export product. Though the anticipated rise in demand for fish and fish products and in aquaculture as a primary means of production has mixed potential benefits for the poor, the link between aquaculture and rural livelihoods as means of sustainable resource exploitation and diversification is considered part of development strategy (Ahmed, 2004). INTAQ, if it proves to be technologically appropriate and economically feasible could be an important component of such strategy.

Notwithstanding these potential benefits, public awareness of INTAQ is low, and in the few cases where there is awareness, INTAQ is not always differentiated from monoculture and suffers from a poor public image. Without better information, information dissemination and direct education of the public, such attitudes will continue to be a major obstacle to the expansion of the practice of INTAQ in the Mediterranean Sea region.

Major requirements for the expansion of this practice

In order to better understand the requirements for expanding INTAQ practice in the Mediterranean Sea region, it is necessary to carefully examine the few instances of INTAQ and near-INTAQ operations in the region and to look for examples outside the region that may be instructive. The focus of this section is to outline the conditions under which INTAQ is feasible and attractive. This section is more normative/prescriptive than the previous ones and focuses on maximizing benefit to all relevant stakeholders; the fish farm as a business; the industry, other users of coastal and marine resources, and regulators and quality of the environment. There is significant site specificity in terms of the needs of a given farm site. The Mediterranean Sea is a large ecosystem and both the physical and ecological carrying capacities vary from place to place making it impossible to provide a "general prescription" type of guideline for technical requirements and day to day operations. Since INTAQ in the region is rare and information scarce and often difficult to obtain, it is also not feasible to prepare a meaningful profile of specific sites and farms. For this reason we proceed with a set of principles and a framework for procedures that will help us to understand the current state of development in INTAQ and the pre-requisites for expanding the practice. In doing so, we distinguish between IMTA and other forms of INTAQ. Such is the case of benthic and pelagic harvesting in the vicinity of farms, cage – artificial reefs combinations and individual farms operating in the proximity of another. This is because, while all forms of INTAQ may have similar environmental benefits, IMTA more often involves a single operator who controls all aspects of investment and production and operates under well defined private property rules. The others may have multiple operators and several types of property rule: for example, two private owners of separate farms; a single private owner operating alongside a public property regime that allows common access to recreational users. In order to fully benefit from the potential of INTAQ, these differences must be considered.

IMTA

Beginning with the experience of IMTA in North America, the lack of commercial application has been attributed to a combination of lack of experience and reluctance on the part of business people to make large-scale commitments in the face of technological, political and economic uncertainty (Taylor, 2004). This belies the relatively high level of interest in the fin- and shellfish monoculture sectors on both coasts of the continent. S. Cross (pers. comm.) is developing a small scale commercial system using private funds and has a business plan for a large-scale, multi-site INTAQ operation. Both systems have generated industry interest but as yet, no commitment. Various others in the field have stressed the challenge of potentially high and variable costs of constructing and operating INTAQ farms as a specific deterrent (M. Ben Yami [Israel], G. Shavit [Israel], S. Cross [Canada], Y. Karakassis [Greece], pers. comm.). S. Cross (pers. comm.) further comments that there may be trade-offs between the investment and operating costs, citing the example of high capital costs of setting up his more "intensive" INTAQ system that requires modifying a steel net-cage salmon system to accommodate shellfish in a system that has a cost-effective automated product handling (grading, harvest and seed deployment). The pilot site is designed to produce approximately 125 tonnes of sablefish, 60 tonnes scallops, 60 tonnes mussels and 20 tonnes of kelp per year. He compares this to the more conventional raft or longline approach used in another three species system in eastern Canada and contends that though less capital cost intensive, it may have higher operating costs. Positive evidence from pilot projects and a clear understanding of the cost and production possibilities are indicated as important steps towards encouraging entry of enterprises. On the production side, the background ecology of the Mediterranean Sea must also be considered and more information is needed on the suitable co-cultivation options in oligotrophic waters in order to allow operators to make informed decisions on diversification at the trophic level.

Facilities that encourage diversification in the market will also encourage diversification in production. Industry and market level initiatives that enable access to many markets will encourage participation at the farm level. Chopin (2006) and Robinson and Chopin (2004) indicate that marine farm products need not compete exclusively with traditional fishery products (46.2 percent molluscs; 44 percent seaweeds; 8.7 percent finfish; 1.0 percent crustaceans and 0.1 percent other animals) and should be seen as a potential source of an array of "bioactive compounds of marine origin" (e.g. pharmaceuticals, nutraceuticals, functional foods, cosmeceuticals, botanicals, pigments, agrichemicals, biostimulants, etc). The European experience points to the need for diversification. Market saturation for common species (salmon, sea bass, and sea bream) is frequent (Fishing in Europe, 2004).

Even if INTAQ is shown to be more profitable and less risky at the market level than monoculture, without a stable, appropriate, well understood regulatory environment, farmers may be reluctant to adopt INTAQ. In the first instance, while the production benefits of INTAQ are of clear interest to farmers, the environmental benefits may not be. One of the reasons that mariculture businesses do not fully recognize the environmental benefits associated with biofiltration is that they accrue in the public sphere. Similarly, the environmental damages caused by monoculture are not considered by firms because they generally have no impact on farms' operations, productivity and profit. Internalizing these environmental costs will provide stronger incentives to marine farmers to adopt practices such as INTAQ. Appropriate regulation should therefore incorporate incentives that recognize the benefits of combining fed and extractive species and encourages practices that do so (Neori *et al.*, 2007).

Second, there is a high degree of uncertainty about INTAQ and its acceptability to regulators. Unless farmers can be reasonably certain that their investment in INTAQ will not be penalized at some future date by new regulation, they will be less likely to adopt it. There is ample evidence from other resource-based sectors showing that operators delay or fail to adopt practices and technologies that are both environmentally preferable and more profitable than conventional practices. Olmstead (1998) documented California farmers' reluctance to invest in water conserving technologies because of skepticism over the water regulator's commitment to supply and price controls. Similarly, Canadian timber producers have been reluctant to commit to practices that while allowing them increased freedom to choose the timing and size of harvests require considerable up-front investment in silviculture. The firms indicate that notwithstanding the expected positive return on their investment, they are uncertain as to whether the policy will remain in place until the growth stock reaches a harvestable age (Freeman, 2003). Given the complicated nature of formal and soft regulation governing aquaculture, the issue needs to be addressed.

Finally, unless INTAQ has a broad base of social acceptance, it will be difficult to foster its expansion, whether by creating an appropriate regulatory framework, or at the grass-roots level. Information dissemination and public education will be the key tools in fostering acceptance. Ridler *et al.* (2007), found favorable attitudes toward INTAQ when survey respondents were informed of its environmental advantages. Robinson and Chopin (2004) in Canada, Whitmarsh (2006) in Scotland and Mazur, Aslin, and Byron (2005) in Australia as well as others have found that environmental impacts are among the major public concerns related to aquaculture. Heuristic evidence from the Mediterranean Sea region points to similar concerns particularly because there is wide use of coastline for tourism activities and therefore, it is possible that an informed public will be more accepting of INTAQ than of other forms of mariculture.

Non-IMTA forms of INTAQ

As soon as there is more than one owner/operator/user, especially when more than one property rights regime is involved, a much wider set of incentives must be considered. In the case of several monoculture farms such as in Olbia, there must be regulatory provisions and techniques that allow for farms to operate in close enough proximity to each other so that detritus from the fed finfish can reach the lower trophic taxa. Examples where this is not the case point to rapid decline in integration benefits. The experiments involving mullets is instructive (Katz *et al.*, 2002) as is evidence from corals which show much higher growth over a limited distance from the fish cage but return to their baseline growth rate at large distances (Bongiorni *et al.*, 2003). This may require specialized design and engineering so that various structures in different farms do not interfere with each other.

Benthic or pelagic harvesting in close proximity to fish cages, especially if it is on the farm site by someone other than the farm owner may also require special provisions such as licenses and agreements with the farmer. More open access activities characteristic of tourism and recreation (e.g. diving around artificial reefs) may be even more complicated. Farmers need to be confident of the security of their site, public officials need to have the safety of other users in mind and depending on the nature of the complementary INTAQ activity and its proximity to the fish farm, the two may be in conflict and creative solutions will be required to ensure that the benefits of INTAQ can be achieved.

CONCLUSIONS AND RECOMMENDATIONS

This report has reviewed the theory and current practice of INTAQ in the Mediterranean Sea. It has used a combination of research, government and professional reports together with direct consultation with researchers and practitioners in the field. The report's objectives were to: describe the current practice of INTAQ in the region and the main factors influencing it; assess INTAQ's strengths and weaknesses in comparison to monoculture using the ecosystem approach and indicate the technological, regulatory, business and other parameters needed to implement INTAQ on a larger scale. The report reviews in detail current practice, relevant industry structures, regulation, environmental issues and information requirements. Because INTAQ is rare in the Mediterranean Sea, we have used, as appropriate, experience from other regions. For the same reasons, we have referred extensively to mariculture and fisheries in general in the discussions of environmental concern and regulation. INTAQ is part of a continuum of practices that exploit marine resources and its impacts on the environment and the fish resource base, and the opportunities it offers for business, industry and communities are best understood in this context.

With respect to several important characteristics, INTAQ compares favorably to monoculture. In terms of ecological carrying capacity, INTAQ's potential for reducing effluent is a significant advantage over monoculture. For the same reason, INTAQ may have a higher degree of social acceptability. INTAQ also offers favorable options for bivalve aquaculture (or other filter feeders) when the vicinity to fish cages provides more food. At the enterprise level, the increase in production together with opportunities for diversification represent important sources of profit and the potential for risk reduction. Feed costs per unit biomass production are lower in INTAQ and there may be operating synergies that lower overall operating costs per unit biomass. The investment required and in particular, the return on investment is difficult to assess, though preliminary case studies have had favorable results.

At the same time, many of the same environmental concerns for monoculture apply to INTAQ as well and these are significant. Also, INTAQ may introduce other risks, such as increased incidence of disease because of the proximity of several species.

Because INTAQ is new and because the environment in which it operates is complex and dynamic, there are many unknowns that need to be resolved in order to confidently assess its potential. Our recommendations below are aimed at this resolution.

Recommendations:

- Establish a metric for comparing various forms INTAQ to other alternatives. This report has provided heuristics but more rigorous comparisons of different types of INTAQ with different types of monoculture that are relevant for the Mediterranean Sea region.
- Increase research at the pilot commercial (rather than theoretical) level to examine the carrying capacity for INTAQ. The research needs to be wide ranging, with specific attention given to the oligotrophic conditions of the Mediterranean Sea and the implications for species selection and nutritional strategies; juvenile production; and overall environmental impact.
- Establish the basis for economic viability and technical feasibility of INTAQ projects in different areas of the Mediterranean Sea.
- Improve information dissemination and in particular public education in order to decrease public opposition to aquaculture in general and to increase understanding of INTAQ in particular.
- Examine the regulatory conditions (formal and soft) suited to the promotion of INTAQ as one of the options for sustainable aquaculture (i.e. incorporating sustainable resource use, economic viability and public benefit). Implement appropriate measures at the regional, national and local levels. Attention to initiatives at the national and local level will be important as these are the levels at which INTAQ takes place, at which opposition occurs and at which direct incentives will be most effective.

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Appendix

KEY EVENTS IN THE EVOLUTION OF ECOSYSTEM MANAGEMENT RELEVANT FOR AQUACULTURE

1900-1980 (6 events)		1981-1989 (13 events)		1990-present (21 events)	
1902	Charter of the International Council for the Exploration of the Sea. Revised 1964, 1970.	1981	Convention for Cooperation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region	1989-91	UN General Assembly Resolutions on Large-Scale Pelagic Driftnet Fishing and its Impacts on the Living Marine Resources of the World's Oceans and Seas
1910	International Commission for the Scientific Exploration of the Mediterranean Sea (ICSEM)	1981	Convention for the Protection of the Marine Environment and Coastal Areas of the South East Pacific.	1990	• Regional Seas Caribbean Protocol on Specially Protected Areas and Species • Convention for a North Pacific Marine Science Organization (PISCES)
1969	Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP)	1982	UN Convention on the Law of the Sea. The comprehensive framework for marine environmental protection and resources conservation.	1991	MARPOL Guidelines for the Designation of Particularly Sensitive Sea Areas (PSSAs)
1971	Convention on Wetlands of International Importance, Especially for Waterfowl (Wetlands or Ramsar Convention). Its "wise use" principle anticipates the concept of sustainable development. Led to the development of the protected areas concept	1982	Protocol on Specially Protected Areas	1992	• UNCED Declaration and Agenda 21 • Convention on Biological Diversity • Convention for the Protection of the Marine Environment of the North East Atlantic • Convention on the Protection of the Marine Environment of the Baltic Sea Area • Convention on the Protection of the Black Sea Against Pollution. Followed by the Black Sea Environment Programme (BSEP) in 1994.
1971	Man and Biosphere Programme (MAB), launched as a program of UNESCO. Contributed to the development of protected areas.	1983	Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region	1994	• Code of Practice on the Introductions and Transfers of Marine Organisms. Supersedes earlier versions of 1973, 1979 and 1990 • Establishment of the Antarctic whale sanctuary
1972	Stockholm Conference on Human Environment. Defined the right of mankind to a healthy environment.	1984	Action Plan for Biosphere Reserves (MAB Programme of IOC) Commission on Environment and Development.	1995	• Global Programme of Action on Protection of the Marine Environment from Land-Based Activities (GPA) • Agreement Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (Fish Stocks Agreement or FSA) • FAO Code of Conduct for Responsible Fisheries • UNESCO Seville Strategy and the Statutory Framework for the World Network of Biosphere Reserves • Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean Sea. Call for protected areas. Supersedes the 1976 Convention.

KEY EVENTS IN THE EVOLUTION OF ECOSYSTEM MANAGEMENT RELEVANT FOR AQUACULTURE

1900-1980 (6 events)		**1981-1989 (13 events)**		**1990-present (21 events)**	
1972	Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention). Covers both natural and cultural areas of outstanding value.	1984 -87	World Commission on Environment and Development	1997	• International Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens
1972	Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention)	1985	International Wildlife Coalition moratorium on whaling	1999	• ITLOS decision regarding Pacific Southern Bluefin Tuna • FAO International Plans of Action (IPOAs) : (1) To reduce the incidental catch of seabirds in long-line fisheries; (2) For the conservation and management of sharks;(3) For the management of fishing capacity.
1973	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Embodies an ecosystem-based approach.	1985	Regional Convention for the Conservation of the Marine Environment of the Red Sea and the Gulf of Aden Environment	2001	• FAO International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing • Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem
1973	FAO Technical Conference on Fisheries Management and Development: stressed overfishing, overcapitalization, environmental degradation (as a risk higher than fishing!) and the need for precautionary, anticipatory and experimental fisheries management. Proposed to frame fisheries management into ocean management	1985	Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region	2002	• Plan of Implementation of the World Summit on Sustainable Development
1979	Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention). Priority work on marine turtles and small cetaceans.	1986	Convention for the Protection and Development of Natural Resources and Environment of the South Pacific Region	2006	General Fisheries Commission for the Mediterranean Sea recommends adoption of Ecosystem Approach to Aquaculture (EAA)
1979	Indian Ocean whale sanctuary	1987	Publication of the Brundlandt Report (Our Common Future). A report of the World	2007	Ecosystem Approach to Aquaculture: Worksop on Definition, Principles and Guidelines, Mallorca, Spain
1980	Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR)	1989	Exxon Valdez oil spill		

Source: mainly Kimball (2001) in Garcia *et al*. (2003).

This technical paper provides a comprehensive review of current integrated mariculture practices around the world in three papers covering temperate zones, tropical zones and one semi enclosed ecosystem, the Mediterranean Sea. Integrated mariculture includes a diverse range of co-culture/farming practices, from integrated multitrophic aquaculture to the more specialized integration of mangrove planting with aquaculture, called aquasilviculture. Modern integrated mariculture systems must be developed in order to assist sustainable expansion of the sector in coastal and marine ecosystems thus responding to the global increase for seafood demand but with a new paradigm of more efficient food production systems. Successful integrated mariculture operations must consider all relevant stakeholders into its development plan, there is also a need to facilitate commercialization and promote effective legislation for the support and inclusion of integrated mariculture through adequate incentives particularly considering the reduction of environmental costs associated to monoculture farming. Bioremediation of fed aquaculture impacts through integrated mariculture is a core benefit but the increase of production, more diverse and secure business and larger profits should not be underestimated as additional advantages.

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