Intelligent Management System for
Integrated Multi-trophic Aquaculture

Policy Brief

EU Potential for IMTA Development

Findings and recommendations from the IMPAQT Horizon 2020 Research and Innovation project https://impaqtproject.eu/

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KEY MESSAGES

- Integrated multi-trophic aquaculture (IMTA) and Low-trophic aquaculture (LTA) provide a route for the sustainable development (environmentally, economically, and socially) of the EU aquaculture sector
- IMTA systems utilise already available nutrients, contributing to circular and recycling processes and reducing the eutrophication potential in cultivation environments
- IMTA systems utilise available space and infrastructure more efficiently (spatial and resource efficiency), enabling an increase in biomass production under a lowered environmental footprint (economic decoupling)
- IMTA production offers an eco-intensification of aquaculture activities with more proteins being obtained per surface area, reducing pressure on the marine space
- Low-trophic species provide biomitigating functions as well as food and monetary value
- IMTA products can increase consumer trust and social license to operate in aquaculture due to their improved environmental profile
- IMTA development is challenged by regulatory and administrative burdens as well as site management and investment encouragement
- IMTA modelling aids planning decisions by both operators and regulators

IMTA AND ITS EUROPEAN POTENTIAL

Development of the EU Aquaculture Sector

Aquaculture is the fastest-growing animal food producing sector in the world and rapidly surpassing wild fisheries as the main source of seafood. Europe's contribution to world aquaculture production is comparatively small although it represents the largest market for fish. With increasing consumption of seafood, the EU remains largely dependent on seafood imports from elsewhere.

Aquaculture plays an important role in European food security, sustainable growth, and employment; as recognised in the adoption of new strategic guidelines for a more sustainable and competitive EU aquaculture (EC, 2021). These set out to build resilience and competitiveness, and to improve the climatic and environmental footprint of the sector, strengthening EU aquaculture in terms of high-quality sustainable seafood production.

In line with the European Green Deal (EC, 2019) and the Farm to Fork Strategy (EC, 2020) the sector is working towards a green transition in the blue bioeconomy by promoting research and innovation, precision aquaculture systems, organic aquaculture, as well as production concepts away from monoculture such as integrated multi-trophic aquaculture, or IMTA. For industries in general, there is a growing demand for more circularity and sustainability in aquaculture production to achieve economic growth while preserving a healthy environment. IMTA is widely recognised as an avenue to enable these transitions, while maintaining and increasing overall productivity and the supply of quality products.

Over 90% of the EU National strategies project growth in aquaculture production (Kane et al., 2018) and thus developing marine spatial plans need to facilitate the inclusion of aquaculture. As an example, Mediterranean and Black Sea states call for the integration of aquaculture into marine spatial plans, along with efficient environmental monitoring and sustainable production systems to improve product health and welfare as well as societal benefits, all of which being desirable benefits across the states. Along with allocated zones for aquaculture, IMTA is a specific concept highlighted to achieve this (Macias et al., 2019).

As production from aquaculture continues to expand there will be challenges linked to demands on the geographical space needed, and current production technologies employed. IMTA systems can utilise the available space and resources more efficiently, enabling an increase in biomass production under a lowered environmental footprint; supported further by the application of tailored monitoring and management technologies for aquaculture.

What is IMTA?

Integrated Multi-Trophic Aquaculture (IMTA) describes a rapidly evolving aquaculture production concept that combines, in the appropriate proportions and scales of management areas, the cultivation of species at two or more different trophic levels such as fed species (finfish, shrimp) with organic extractive species (shellfish and other invertebrates, herbivorous fish) and inorganic extractive species (microalgae, macroalgae i.e. seaweeds, plants) (Chopin, 2021).

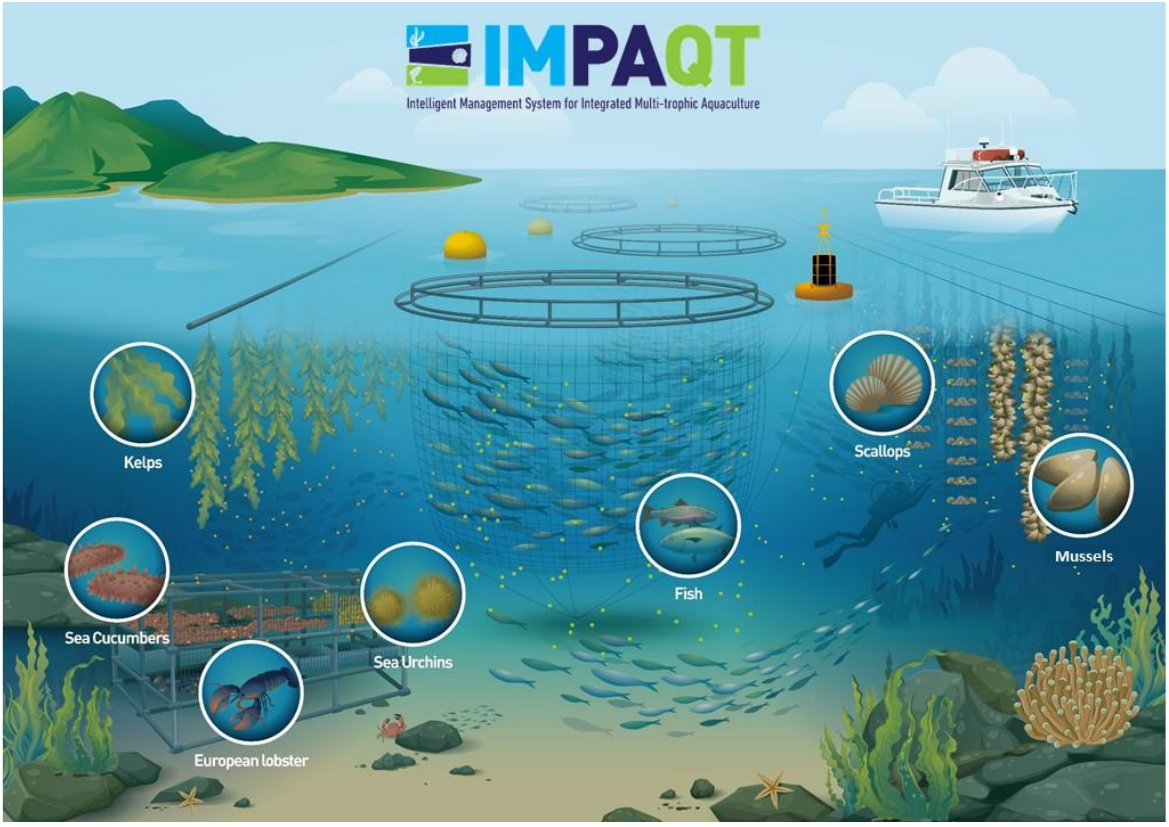


Figure 1. IMTA system. Cultivation of different trophic levels:
fed species, organic extractive species and inorganic extractive species

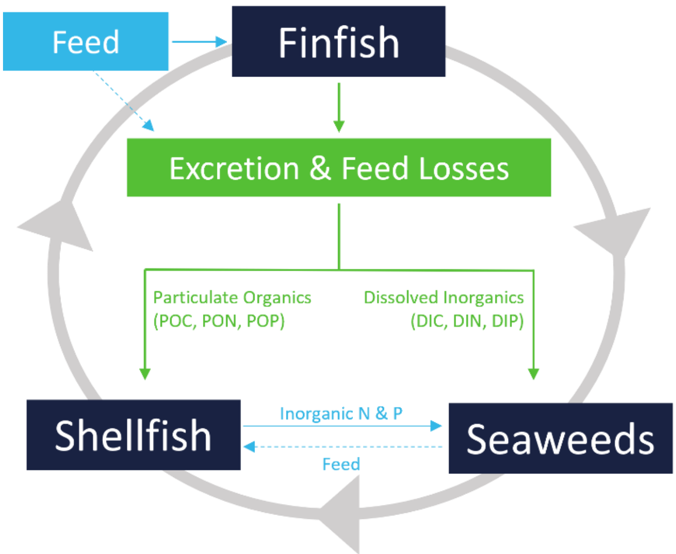


Figure 2. IMTA concept. In IMTA farms the uneaten feed and wastes, nutrients, and by-product are recaptured and converted into harvestable and healthy seafood.

IMTA is a concept, not a formula, with not one ultimate IMTA system definition but rather a multitude of variations resulting from local differences (climatic, environmental, biological, physical, chemical, economic, historical, societal, political, regulatory, and jurisdictional), leading to diverse choices in the design of the best locally suited IMTA systems. A related concept to IMTA is low-trophic aquaculture (LTA) which describes the production of lower trophic species groups such as shellfish and/or seaweeds while excluding finfish.

The co-cultivation of multiple species in one area has been practised for centuries in Asia, such as LTA of seaweeds and shellfish along the coastlines of China and Korea. Such practices are comparatively novel to the Western world including European coastlines, where aquaculture operations are largely dominated by monoculture. Over the past two decades, however, awareness about the **limitations and risks associated with large-scale monoculture** (e.g. ecosystem impacts, habitat destruction, risk of eutrophication, elevated disease susceptibility) has increased, as has the need for a more sustainable and holistic approach to seafood production.

IMTA and LTA species are selected based on their complementary ecosystem functions to **create balanced systems for environmental sustainability** (biomitigation and bioremediation), **economic stability** (product diversification and risk reduction), **and social acceptability** (better management practices).

IMTA DEVELOPMENT ACROSS EUROPE

IMTA development in Europe is largely driven by research initiatives yet relies on the transition from scientific evidence to a practising community, for large-scale commercial systems in particular (Falconer et al., 2019). IMTA trials (experimental or small commercial scale) are predominantly performed at existing aquaculture sites, by either modifying finfish sites for the co-cultivation with non-fed extractive species or by exploiting the additional potential of existing infrastructure such as growing seaweeds at shellfish farms and vice versa.

Previous pan-European projects have implemented IMTA sites demonstrating the benefits and identifying challenges for its uptake (IDREEM project 2014-2015; http://www.idreem.eu/cms/home/) (Hughes et al., 2016), as well as developing learning materials to promote knowledge exchange and communication with regulators (INTEGRATE project 2017-2020; http://integrate-imta.eu/). Building upon this work, the IMPAQT project (2018-2021; https://impaqtproject.eu/) implemented IMTA systems, in addition to the development and employment of precision aquaculture tools to validate a more efficient, sustainable, and circular aquaculture production model (see info box – IMPAQT Project).

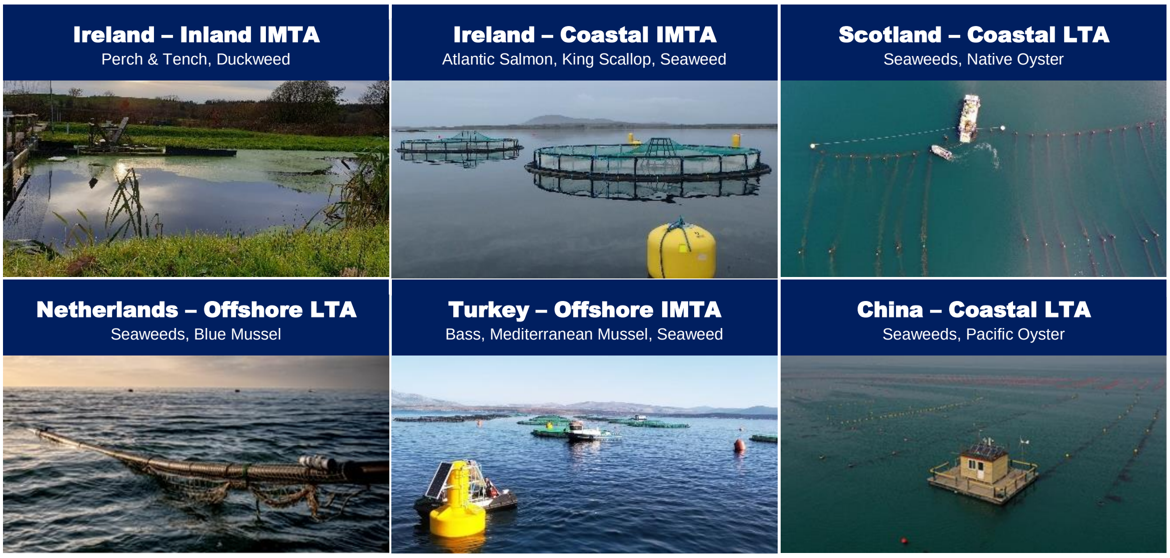


Figure 3. IMPAQT pilot sites for demonstrating IMTA system configurations in Europe and beyond

IMPAQT - Intelligent Management System for Integrated Multi-Trophic Aquaculture

21 partners from 12 countries & 6 IMTA systems

IMPAQT developed and validated in-situ a **multi-purpose** (inland, coastal, and offshore), **multi-sensing** (heterogeneous sensors and new emerging technologies) and **multi-functional** (advanced monitoring, modelling, data analytics and decision making) **management platform for sustainable IMTA production**.

Different IMTA system configurations have been implemented across Europe and beyond, ranging from LTA to full-scale IMTA systems at both research and commercial aquaculture sites. These IMTA pilots were equipped with novel sensors, data sources and smart systems required for long-term autonomous monitoring, and data submitted to the novel integrated management system (IMS). The IMS comprises analytics and decision support functionalities for enhanced data-driven decision-making for production optimization, environmental protection, animal welfare and food quality assessment at IMTA farm scale. An advanced IMTA model further provided spatially explicit information on how the different farm components interact with the environment on the scale of an ecosystem which can be used for planning decisions by both farmers and regulators (see Info box – IMTA Model).

Project outcomes support the eco-intensification of EU aquaculture by demonstrating eco-efficiency, lowered environmental impacts, socio-economic benefits, ecosystem services enabled by IMTA, as well as the transition towards a circular economy business model.

Key IMPAQT findings, IMTA system benefits as well as remaining challenges to drive IMTA implementation in Europe are presented here.

IMTA for Circularity and Sustainability

The aquaculture industry plays an important role in facilitating a sustainable bioeconomy and circular economy through business development and diversification (e.g. exploiting the potential for innovation in culture techniques, technological advances, species and product diversification). With sustainability, efficiency and productivity being intrinsically linked, the IMPAQT project adopted a **holistic approach to investigate the environmental, economic, and societal impacts of transitioning to IMTA production systems**.

Environmental Impact under a Life Cycle Perspective

Considering the overall life cycle impact associated with IMTA systems, the biomass production in multi-trophic conditions has environmental benefits compared to monoculture production due to a more efficient use of resources. **Synergies in infrastructure elements, inspection activities, and harvesting operations** lead to a **reduction in the overall environmental impacts in terms of biomass production**. Particularly, environmental benefits associated with the multi-trophic systems are commonly related to the **eutrophication reduction potential**, and the improved environmental profile of IMTA products. Together with eutrophication, **climate change impact is generally reduced in IMTA systems**; this is when the environmental impact assessment (EIA) considers the carbon absorption by seaweed, and the scope ends at farm gate. Spatial IMTA systems mean an **eco-intensification of the aquaculture activities** where more proteins are obtained per surface area, reducing the environmental pressure on marine spatial use.

Environmental impacts largely depend on the production infrastructure and practices employed. Optimisation of IMTA activities can lead to a notable reduction of environmental impacts. For example, efficient feeding systems reduce negative impacts associated with feed losses (resource efficiency, reduced nutrient enrichment). Further innovations in farm infrastructure components are desired to limit environmental impacts arising from the dominant use of plastics and nylon structures, in LTA systems in particular.

The integrated management system developed and employed in IMPAQT assists in farm management facilitating optimal biomass, exploiting the nutrient capture and bioremediation capacity for extractive species.

Ecosystem Services

The true **value of IMTA lies in the benefits and ecosystem services provided by low-trophic species.** Besides offering food values and additional biomass, they provide biomitigating functions to alleviate the adverse impacts caused by aquaculture waste on the environment and aquatic species. They further contribute to an **increase in consumer trust in aquaculture** and to the societal (and political) license for the industry to operate. This can shift the perception of an industry from being largely fish dominated monoculture, to a more holistic approach to commercial farming.

Circular Economy & Socio-Economy

IMTA makes use of a free source of nutrients otherwise wasted, and thus, cultivation components play a key role in recycling processes within the system. In this sense, IMTA meets the characteristics of the organic feedstock Circular Economy Business Model (CEBM; Lüdeke-Freund et al., 2018) where biomass conversion provides inputs for other production processes. Given that the circularity is a driver for sustainability, circular models around IMTA systems promote the sustainability of aquaculture. To create circular value for such production models, cultivation activities, resource management and stakeholders involved are all relevant. Granting permits, understanding the biological systems involved, system monitoring, and optimizing cultivation practices are some of the early actions needed for the optimal circularity in the system. Circularity along the value chain requires close collaboration between regulators and system designers to enable and improve the profitability and sustainability of IMTA farms.

A socio-economic assessment found a significant contribution of IMTA systems to local economy development, offering new labour competences and income potential. There is potential for collaboration through the establishment of networks and synergistic action plans to address knowledge gaps and future developments in IMTA production and product marketing.

Benefits of IMTA production

Species & Product Diversification	• Increased ecological diversity and productivity • Production all year around versus seasonality in monoculture • Reduced environmental impact • Increased investment portfolio (added economic value) • Reduced economic risk
Spatial Efficiency	• More optimal use of existing cultivation space • Increased biomass production • Reduced environmental impacts in comparison to monoculture
Nutrient Budget	• Uptake of surplus nutrients and organic matter by extractive species • Conversion of 'waste' to 'food' for additional growth and end products • Increase in the sustainability and circularity of the process
Site Economics	• Lower operating costs for non-fed species • IMTA investment distributed across species and resulting income potential • Cost-effective capital investment due to shared resources and technologies • More efficient resources management through economies of scale (savings in labour cost due to new automated activities) • Increased consumer trust and social license to operate due to improved environmental credentials

IMTA Model – A Planning Tool

The benefits of IMTA farming depend on the scale of its application and the characteristics inherent to the receiving environment. During the farm design stage, IMTA models help to understand and predict the systems benefits and limitations (for example estimating the expected growth of co-cultured species and quantifying the potential of waste recovery and/or transformation), whilst indirectly addressing aspects of economic diversity, site profitability and social acceptability. Particularly for IMTA set-ups with only extractive aquaculture, such models can aid to assess the ecological carrying capacity of the system, by calculating the impact of aquaculture set-ups on nutrient cycling and primary production of phytoplankton over a growing cycle.

IMPAQT developed two IMTA models for contrasting offshore environments with different species configuration:

- **Dutch North Sea LTA Model** – effects of combined seaweed (*Saccharina latissima*) and mussel (*Mytilus edulis*) production in a nutrient-rich environment with high current velocities and thus short residence times.
- **Aegean Sea IMTA Model** – effects and benefits of fish farming in combination with seaweeds (*Ulva rigida*) and mussel (*Mytilus galloprovincialis*) production in an oligotrophic environment with little freshwater input.

The models provide valuable information on far-field interactions between the environment and IMTA farm components and, with continuing validation, can be **used for decision-making by farm operators (site management) and regulators (ecosystem management)** alike. IMPAQT proposes a **blueprint for IMTA models** addressing modelling requirements and potential applications.

The requirements inform about validation and calibration data needed from relevant environmental variables as well as the extent and resolution of the model grid applied. The application potential of IMTA models is multi-functional. Farm operators can use it for decision support during the planning and cultivation stage as well as to provide evidence to third parties. Regulators can consult IMTA models for information about responsible levels of fed and extractive aquaculture in an ecosystem, further assisting licensing procedures for IMTA set-ups as well as certification schemes for social acceptance. Model outputs can also be used in stakeholder engagements concerning marine spatial planning decisions.

CHALLENGES FOR IMTA

IMTA challenges identified in IMPAQT mainly concern regulatory burdens as well as site management decisions and are largely consistent with findings of related pan-European IMTA projects (e.g. IDREEM, Integrate).

Licensing and Regulatory Harmonization

The EU aquaculture sector identifies administrative burdens as important barrier to growth (EC, 2021). Licensing systems differ across most EU Member States - they are complex and lack predictability in terms of processing time and expected outcome. Applications include aspects of site location and scale, production type, species in culture, environmental impact, and social acceptability. Fully commercial systems generally undergo more extensive requirements as compared to solely experimental sites as these are producing seafood for the consumer's market and thus having to address aspects related to food safety. Seaweed cultivation, whether experimental or commercial, remains novel for many EU countries, causing **uncertainty in licensing procedures; even more so when applying for non-monoculture systems (LTA and/or IMTA).**

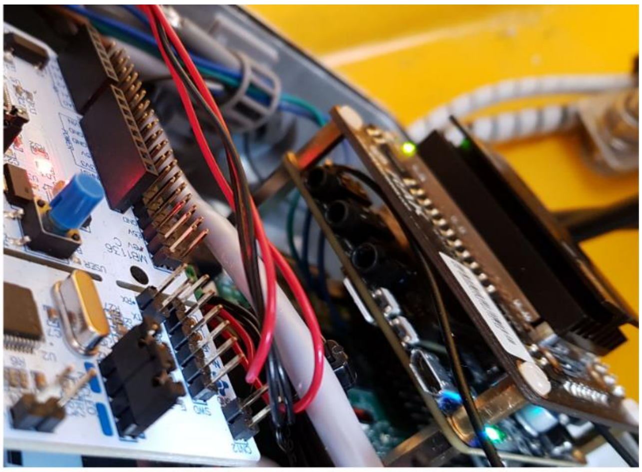
In general, regulations related to IMTA are lacking harmonization between different national regulatory frameworks. Whilst it may be possible to obtain permission for small-scale experimental IMTA systems, the regulatory framework in most EU Member States currently represents a significant barrier to the development of commercial-scale IMTA operations (Hughes et al., 2016). Even for small-scale experimental sites, IMPAQT found that amending an existing license for inclusion of another species group was not straight-forward; overall being simpler when adding seaweed to a shellfish site than vice versa as experienced by the Scottish pilot site. Here, shellfish sites are located in shellfish growing waters, managed by the relevant authorities with regular monitoring for biotoxins and biohygiene. As such, the addition of seaweeds does not pose adverse impacts on the surrounding environment but can rather improve the water quality.

Administrative procedures for aquaculture need to be simplified on a national level, especially in view of transitioning to multi-species systems for the sustainable development of the sector. Responsibilities and processes should be streamlined and harmonised, for example by providing a single platform accessible by all authorities including the applicant allowing to be informed about the required next steps and information to be provided, and to track progress.

Cultivation Site Potential

Prominent policy requirements are for the integration of aquaculture into marine spatial plans, for efficient environmental monitoring, and to utilise environmentally friendly production systems. For an aquaculture facility to function, environmental monitoring needs to be carried out and having quality environmental data available for the operation is critical. **Aquaculture sites can be valuable sources of environmental data** within their operational area and considering that there is generally a paucity of data on many specific areas, such source will be a substantial contribution to the regional and national efforts outlined in the Marine Strategy Framework Directive (MSFD) objectives on good environmental status (GES).

IMPAQT showed that improved and emerging technologies, developed and employed to the operator's needs, not only provide the data to improve current production practices but can also provide much needed knowledge (e.g. species synergies, environmental status, seafood quality and safety) to regulatory bodies to inform policy and standardisation procedures.



RECOMMENDATIONS TO POLICY

- Promote **experimental IMTA systems** to address knowledge gaps relevant to both operators and regulators
- Develop **best practice guidelines for IMTA production** addressing aspects of site- and species selection as well as system configuration
- Support **IMTA modelling as planning, decision-support and information tool** for operators and regulators
- Promote **research and innovation for IMTA development** in the EU, including new and emerging technologies and innovation for infrastructure components, operational monitoring and management
- Encourage **knowledge exchange centres** and education material for IMTA and LTA production
- Assist procedural changes by providing information on what IMTA and LTA contribute to the sector
- Facilitate **circularity in aquaculture** through business development (production and monitoring innovations) and species/product diversification
- Lower regulatory burdens by **streamlining licencing procedures on a national level**
- Integrate **aquaculture in marine spatial planning**

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Contributors

Kati Michalek[1]*, Frank Kane[2]*, Michele S. Stanley[1], Inmaculada Sánchez[3], Seyma Tarkan[4], Kemal Can Bizel[5], George Malindretos[6], Luca A. van Duren[7]

*corresponding authors: frank.kane@marine.ie, kati.michalek@sams.ac.uk

Affiliations

[1] Scottish Association for Marine Science (SAMS), Oban, Argyll, UK

[2] Marine Institute, FEAS Aquaculture Section, Oranmore, Ireland

[3] Leitat Technological Centre, Terrassa (Barcelona), Spain

[4] Çamli Yem, Feed and Animal Husbandry, Izmir, Turkey

[5] Dokuz Eylül University, Institute of Marine Sciences and Technology (DEU-IMST), Izmir, Turkey

[6] Harokopio University of Athens, Greece

[7] Deltares, Delft, The Netherlands

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IMPAQT Consortium