Study on state-of-the-art scientific information on the impacts of aquaculture activities in Europe

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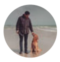

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Study on state-of-the-art scientific information on the impacts of aquaculture activities in Europe

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Acronym	Definition
AAC	Aquaculture Advisory Council
AHD	Acoustic harassment device
ALART	Aquaculture Law Assessment and Revision Tool (FAO)
ALDFG	Abandoned, lost or otherwise discarded gear
AMR	Antimicrobial resistance
API	Associazione Piscicolturi Italiani (Italian Aquaculture Producers Association)
APN	Anti-predator netting
APROMAR	Asociación Empresarial de Acuicultura de España (Spanish Aquaculture Business Association)
ARG	Antibiotic resistance gene
AWI	Alfred Wegener Institute
BACI	Before-after-controlled impact
BOD	Biochemical oxygen demand
CAPDS	Consejería de Agricultura, Pesca y Desarrollo Sostenible (Ministry of Agriculture, Livestock, Fisheries and Sustainable Development)
CAS	Chemical Abstracts Service
CEPESCA	Confederación Española de Pesca (Spanish Fisheries Federation)
CFP	Common Fisheries Policy (EU)
CINEA	European Climate, Infrastructure and Environment Executive Agency
CITES	Convention on International Trade in Endangered Species
COD	Chemical oxygen demand
DCF	Data Collection Framework (EU)
DEHP	di(2-ethylhexyl)phthalate
DG MARE	Directorate-General for Maritime Affairs and Fisheries
DIC	Dissolved inorganic carbon
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorous
DMSP	Dimethylsulfoniopropionate
DNRA	Dissimilatory nitrate reduction to ammonia
DPMA	Direction des Pêches Maritimes et de l'Aquaculture (Department of Maritime Fisheries and Aquaculture)
DSP	Diarrhoetic shellfish poisoning
EASME	Executive Agency for Small and Medium-Sized Enterprises
EEA	European Economic Area
EFSA	European Food Safety Authority
EIA	Environmental impact assessment
EMFAF	European Maritime Fisheries and Aquaculture Fund
EMFF	European Maritime and Fisheries Fund
EQS	Environmental quality standards

Acronym	Definition
EU	European Union
EU-MAP	EU Multi-annual Plan
EUMOFA	European Market Observatory for Fisheries and Aquaculture
EWG	Expert working group
FAO	Food and Agriculture Organization of the United Nations
FTE	Full-time equivalent
GM	Genetically modified
IMTA	Integrated multi-trophic aquaculture
IUCN	International Union for Conservation of Nature
MSCD	Mussel seed collection device
MSP	Maritime spatial planning
MTF	Model trout farm
NGO	Non-government organisation
NNS	Non-native species
PGECON	Planning Group on Economic Issues
PTRs	Ponds, tanks and raceways
RAS	Recirculating aquaculture system
SAC	Special Areas of Conservation
STECF	Scientific, Technical and Economic Committee for Fisheries (EU)
SPA	Special Protected Area
TFEU	Treaty on the Functioning of the European Union

EXECUTIVE SUMMARY

Aquaculture is one of the world's fastest-growing industries, with 6 % annual growth since 2010, and is becoming an increasingly important component of the world's food production. European aquaculture has not kept up with the pace of change in other parts of the world, growing only 24 % since 1990, and only 6 % since 2007. As with all food production industries, aquaculture has a range of positive and negative impacts for the environment and the socio-economic system, which varies across production type, species, geography and biophysical context.

The overall purpose of this study is to present the scientific basis of the positive and negative impacts of European aquaculture from an economic, environmental and social point of view, in order to facilitate a well-informed debate. However, the study does not seek to assess the magnitude or likelihood of impacts, compare magnitude or likelihood of impacts among different types of aquaculture nor compare the impacts identified to those of alternative food production systems.

In order to achieve this aim, the project first undertook an extensive literature review to collate state-of-the-art scientific information on the positive and negative impacts of aquaculture. The study examined scientific peer-reviewed literature, supplemented by the Scientific, Technical and Economic Committee for Fisheries and European Data Collection Framework for aquaculture and focused on finfish culture (sea cages; ponds, tanks, and raceways; and recirculating aquaculture systems), shellfish culture (suspended, trays, and bottom culture), macroalgae and microalgae.

To complement the impacts derived from the scientific literature a deeper analysis of impacts was conducted via 18 case studies across Denmark, Germany, France, Poland, Netherlands, Croatia, Greece, Ireland, Italy, Portugal and Spain. The case studies covered a range of production technologies and species types. The case studies were used to verify impacts identified in the scientific literature, to identify any impacts potentially overlooked by the scientific literature and to identify legislation and mitigation relevant to the aquaculture type at the national level. The case studies combined information from the literature review, supplementary scientific and grey literature of specific relevance to the case study, and key expert interviews (40 in total). Key experts consulted were primarily those from relevant national authorities and national research institutes.

In parallel with the case studies, a review of the EU and national regulatory frameworks and associated mitigation measures was conducted. The review and the key expert interviews from the case studies were used to provide a preliminary analysis of the extent to which the regulatory framework mitigates negative impacts from aquaculture.

The information from the literature reviews and the case studies was then collated and evaluated to provide an overview of the most important and most broadly identified positive and negative impacts for different aquaculture types. The evaluation made specific efforts to highlight consensus between the scientific literature and the opinions of key experts, as well as highlighting where these differ – indicating potential priority areas for future research.

The aquaculture impacts identified are predominantly environmental in nature. This is likely a result of the search parameters used in the scientific literature review, the interests of the academic sector and the interests of research-funding institutions. The scientific literature did not often address the social or economic impacts of aquaculture in the EU, nor the legislation relevant for the sector. The metadata shows clearly that finfish aquaculture has received the greatest attention in the scientific literature (56.0 %), followed by shellfish (30.2 %), with algae (both macroalgae and microalgae) receiving the least (13.8 %) attention. Algal culture at commercial scale is relatively new in the EU and, in the case of microalgae, often restricted to laboratory environments. It is therefore unsurprising that algal aquaculture has received relatively little attention. Despite shellfish culture having been established for longer than finfish culture, it has received less academic attention in the last ten years, possibly a reflection of its comparatively smaller value and lower level of perceived and/or potential environmental impact. The finfish-associated scientific literature is dominated by negative impacts (70.6 %), the shellfish scientific literature is balanced between positive (56.0 %) and negative impacts (44.0 %), and the algal (micro- and macroalgae) scientific literature indicates mostly positive impacts (87.5 %). There is evidence of clear consensus between the scientific literature and key experts on a number of prominent impacts from aquaculture, which underscores their importance.

In terms of positive impacts, both the scientific literature and key experts clearly acknowledge the importance of aquaculture in providing greater access to seafood, alongside the associated benefits to food security, food quality and health and nutrition. This improved access has also likely contributed to a reduction, or at least stabilisation, of pressure on wild stocks where aquaculture is able to meet an increasing proportion of demand from consumers. Employment, particularly of low-skilled nationals often in rural areas, is another key positive impact of the aquaculture sector. However, the lack of contemporary expansion in the EU's aquaculture sector means there is a stable, rather than growing, number of enterprises and slowly declining employment in the sector.

Conversely, there is broad consensus within scientific literature and among key experts about the potential for in situ aquaculture to result in the introduction of non-native species, and the potential weakening of wild stock fitness through genetic introgression of farmed and wild stock through either escapes and subsequent breeding (finfish) or the release of gametes/spat into the local environment (shellfish and macroalgae). The scientific literature and key experts remain concerned about the use of pesticides, chemicals and medicines to control parasites and infection across finfish, and to a much lesser extent shellfish and algal aquaculture, particularly as this relates to the development of anti-pesticide and anti-microbial resistance in disease-causing parasites and microbes. While regulations for the use of these substances are in place, there is still uncertainty about the long-term effects and implications of even controlled exposure. The scientific literature and key experts expressed the importance of effluent discharge, either as dissolved matter or solid organic matter, and its potential for localised impacts to biochemical cycles, nutrient loads and community structure. Both perspectives acknowledge the small area of impact of effluent release at current culture densities but express concern on the occurrence of substantial increases in current aquaculture activities, particularly if aquaculture sites are closely clustered or densities are increased.

In addition, key experts expressed concerns more broadly around animal welfare in aquaculture settings. Animal welfare is an increasingly prominent topic in the public eye and within the aquaculture sector. Animal welfare did not appear prominently in the scientific literature, likely reflecting continued debates around wider issues such as the ability or not of fish to feel pain rather than a true lack of scientific interest within the aquaculture sphere. Key experts also expressed concern about the potential impacts of abandoned, lost or otherwise discarded gear from aquaculture, especially in the culture of shellfish and macroalgae (suspended cultures). This concern forms part of the more general topic of anthropogenic litter, which is of wide and increasing scientific, sectoral and public interest. Lastly, key experts identified a number of infrastructure impacts that relate to the siting of aquaculture facilitates, which are not well addressed by the scientific literature, likely reflecting a lack of wider scientific interest rather than a lack of importance.

The regulatory framework that addresses the potential negative impacts of the aquaculture sector in the EU is diverse and extremely complex. It includes a wide range of instruments adopted at the EU level as well as Member State legislation. In addition, site-specific measures to address negative impacts are usually contained in the specific licence conditions of each individual aquaculture facility. This complexity arises for three main reasons. First, the sheer diversity of the aquaculture sector itself in terms of: (a) the species cultured; (b) the habitat in which aquaculture is undertaken; (c) the type of technology used; and (d) the scale of production. Different legal rules may typically apply depending on each of these factors. Second, apart from legislation that has aquaculture as its specific focus, aquaculture takes place within, and is subject to the rules of a much broader legal framework that addresses diverse matters such as land-use planning/development, coastal zone management, employment and health and safety issues and many more. Lastly, unlike marine capture fisheries, aquaculture is not an exclusive EU competence.

The review of the EU and Member State regulation demonstrates that the existing framework seeks to regulate impacts in line with best practice. Further, it demonstrates that, in general terms, the regulatory framework is quite effective in mitigating many of the negative environmental and social impacts of aquaculture in the EU in part, if not entirely, in some cases. However, there are areas emerging in which there is room to strengthen or further develop the regulatory framework. Specific concerns remain around the regulation of impacts on animal welfare (beyond the controls of stocking density and disease/parasites) and of the framework surrounding the aquaculture of macro- and microalgae.

Aquaculture is an established practice in Europe. While some concerns remain around the negative impacts across production systems, the positive impacts derived from aquaculture and the comprehensive regulatory framework surrounding it must be acknowledged. However, if the EU's aquaculture sector is able to achieve new growth, vigilance must be maintained via continued research, monitoring, technological innovation, and mitigation to counteract emerging or existing negative impacts, supported by a regulatory framework that encourages the development of lower-impact production processes for finfish, bivalves and algae. Parallel to this, given that public perception of aquaculture does not match the evidence, open and transparent communication around aquaculture should be considered a priority to dispel 'myths' whilst being upfront about the pitfalls. A variety of positive impacts are currently studied in the context of ecosystem services, which needs further development and contextualisation for further enhancement and facilitation of benefits and social perception.

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RÉSUMÉ EXÉCUTIF

Avec une croissance annuelle de 6 % depuis 2010, l'aquaculture est l'une des industries à la croissance la plus rapide au monde et devient une composante de plus en plus importante de la production alimentaire mondiale. L'aquaculture européenne n'a pas suivi le rythme des changements dans d'autres parties du monde, avec une croissance de seulement 24 % depuis 1990 et de seulement 6 % depuis 2007. Comme pour toutes les industries de production alimentaire, l'aquaculture présente un panel de répercussions positives et négatives sur l'environnement et le système socio-économique, qui varient selon le type de production, l'espèce, la géographie et le contexte biophysique.

L'objectif global de cette étude est de présenter la base scientifique des répercussions positives et négatives de l'aquaculture européenne d'un point de vue économique, environnemental et social, afin de faciliter un débat bien informé. Cependant, l'étude ne cherche pas à évaluer l'ampleur ou la probabilité des répercussions, à comparer l'ampleur ou la probabilité des répercussions entre différents types d'aquaculture ni à comparer les répercussions identifiées à ceux des systèmes de production alimentaire alternatifs.

Afin d'atteindre cet objectif, le projet a d'abord entrepris une analyse documentaire approfondie afin de rassembler des informations scientifiques de pointe sur les répercussions positives et négatives de l'aquaculture. L'étude a examiné une littérature scientifique évaluée par des pairs, complétée par le Comité scientifique, technique et économique de la pêche et le Cadre européen de collecte de données pour l'aquaculture et axée sur la culture des poissons (cages marines ; étangs, réservoirs et circuits ; et systèmes d'aquaculture en recirculation), la conchyliculture (en suspension, plateaux et culture de fond), les macroalgues et les microalgues.

Pour compléter les répercussions présentées dans la littérature scientifique, une analyse plus approfondie des répercussions a été menée à travers 18 études de cas au Danemark, en Allemagne, en France, en Pologne, aux Pays-Bas, en Croatie, en Grèce, en Irlande, en Italie, au Portugal et en Espagne. Les études de cas couvraient un éventail de technologies de production et de types d'espèces. Les études de cas ont été utilisées pour vérifier les répercussions identifiées dans la littérature scientifique, pour identifier les effets potentiellement négligés par la littérature scientifique et pour identifier la législation et les mesures d'atténuation pertinentes pour le type d'aquaculture au niveau national. Les études de cas combinaient des informations provenant de la revue de la littérature, de la littérature scientifique et parallèle supplémentaire présentant un intérêt particulier pour l'étude de cas et des entretiens avec des experts clés (40 au total). Les principaux experts consultés étaient principalement ceux des autorités nationales compétentes et des instituts de recherche nationaux.

Parallèlement aux études de cas, un examen des cadres réglementaires européens et nationaux et des mesures d'atténuation associées a été effectué. L'examen et les entrevues avec les principaux experts tirés des études de cas ont été utilisés pour fournir une analyse préliminaire de la mesure dans laquelle le cadre réglementaire atténue les effets négatifs de l'aquaculture.

Les informations issues des revues de littérature et des études de cas ont ensuite été rassemblées et évaluées afin de donner un aperçu des effets positifs et négatifs les plus importants et les plus largement identifiés pour différents types d'aquaculture. L'évaluation a déployé des efforts spécifiques pour mettre en évidence le consensus entre la littérature scientifique et les opinions d'experts clés, ainsi que pour mettre en évidence les domaines de divergence potentiels – indiquant les domaines prioritaires potentiels pour la recherche future.

Les répercussions aquacoles identifiées sont principalement de nature environnementale. Cela est probablement dû aux paramètres de recherche utilisés dans la revue de la littérature scientifique, aux intérêts du secteur universitaire et aux intérêts des institutions de financement de la recherche. La littérature scientifique n’a pas souvent abordé les effets sociaux ou économiques de l’aquaculture dans l’UE, ni la législation pertinente pour le secteur. Les métadonnées montrent clairement que la pisciculture a reçu la plus grande attention dans la littérature scientifique (56.0 %), suivie des mollusques et crustacés (30.2 %), les algues (macroalgues et microalgues) recevant le moins d’attention (13.8 %). La culture des algues à l’échelle commerciale est relativement nouvelle dans l’UE et, dans le cas des microalgues, souvent limitée aux environnements de laboratoire. Il n’est donc pas surprenant que l’aquaculture d’algues ait reçu relativement peu d’attention. Bien que l’élevage de mollusques et crustacés ait été établi depuis plus longtemps que l’élevage de poissons, il a reçu moins d’attention de la part des chercheurs au cours des dix dernières années, ce qui reflète peut-être sa valeur comparativement plus faible et son niveau inférieur d’impact environnemental perçu et/ou potentiel. La littérature scientifique associée aux poissons est dominée par les répercussions négatives (70.6 %), la littérature scientifique sur les mollusques et crustacés est équilibrée entre les répercussions positives (560 %) et négatives (44.0 %), et la littérature scientifique traitant des algues (micro et macroalgues) indique des répercussions principalement positives (87.5 %). Il existe des preuves d’un consensus clair entre la littérature scientifique et les experts clés sur un certain nombre de répercussions importantes de l’aquaculture, ce qui souligne leur importance.

En termes de répercussions positives, la littérature scientifique et les experts clés reconnaissent clairement l’importance de l’aquaculture pour offrir un meilleur accès aux fruits de mer, ainsi que les avantages associés à la sécurité alimentaire, à la qualité des aliments, à la santé et à la nutrition. Cette amélioration de l’accès a également probablement contribué à une réduction, ou du moins à une stabilisation, de la pression sur les stocks sauvages où l’aquaculture est en mesure de répondre à une proportion croissante de la demande des consommateurs. L’emploi, en particulier des ressortissants peu qualifiés, souvent dans les zones rurales, est un autre impact positif clé du secteur de l’aquaculture. Cependant, l’absence de croissance contemporaine dans le secteur aquacole de l’UE signifie qu’il y a un nombre stable, plutôt que croissant, d’entreprises et une baisse lente de l’emploi dans le secteur.

Inversement, il existe un large consensus au sein de la littérature scientifique et parmi les principaux experts sur la possibilité pour l’aquaculture in situ d’entraîner l’introduction d’espèces non indigènes et l’affaiblissement potentiel de l’aptitude des stocks sauvages par l’introgression génétique des stocks d’élevage et sauvages par des évasions et une reproduction ultérieure (poissons à nageoires) ou la libération de gamètes / naissains dans l’environnement local (mollusques et crustacés et macroalgues). La littérature scientifique et les principaux experts demeurent préoccupés par l’utilisation de pesticides, de produits chimiques et de médicaments pour lutter contre les parasites et les infections chez les poissons à nageoires et, dans une bien moindre mesure, par l’aquaculture de mollusques et d’algues, en particulier en ce qui concerne le développement d’une résistance aux antiparasitaires et aux antimicrobiens chez les parasites et les microbes pathogènes. Bien que des règlements sur l’utilisation de ces substances soient en place, il subsiste de l’incertitude quant aux effets et aux répercussions à long terme d’une exposition même contrôlée. La littérature scientifique et les principaux experts ont exprimé l’importance du rejet d’effluents, que ce soit sous forme de matière dissoute ou de matière organique solide, et son potentiel de répercussions localisées sur les cycles biochimiques, les charges en nutriments et la structure de la communauté. Les deux perspectives reconnaissent la faible zone d’impact du rejet d’effluents aux densités de culture actuelles, mais s’inquiètent de l’occurrence d’augmentations substantielles des activités aquacoles actuelles, en particulier si les sites aquacoles sont étroitement regroupés ou si les densités sont augmentées.

En outre, des experts clés ont exprimé des préoccupations plus générales concernant le bien-être des animaux dans les milieux aquacoles. Le bien-être animal est un sujet de plus en plus important aux yeux du public et dans le secteur de l'aquaculture. Le bien-être animal n'est pas apparu en bonne place dans la littérature scientifique, reflétant probablement des débats continus autour de questions plus larges telles que la capacité ou non des poissons à ressentir de la douleur plutôt qu'un véritable manque d'intérêt scientifique dans la sphère aquacole. Les principaux experts se sont également dits préoccupés par les impacts potentiels des engins abandonnés, perdus ou autrement mis au rebut provenant de l'aquaculture, en particulier dans la culture des mollusques et crustacés et des macroalgues (cultures en suspension). Cette préoccupation fait partie du sujet plus général des déchets anthropiques, qui présente un intérêt scientifique, sectoriel et public large et croissant. Enfin, des experts clés ont identifié un certain nombre de répercussions sur les infrastructures liés à l'implantation de facilités aquacoles, qui ne sont pas bien abordés par la littérature scientifique, reflétant probablement un manque d'intérêt scientifique plus large plutôt qu'un manque d'importance.

Le cadre réglementaire qui traite des impacts négatifs potentiels du secteur de l'aquaculture dans l'UE est diversifié et extrêmement complexe. Il comprend un large éventail d'instruments adoptés au niveau de l'UE ainsi que la législation des États membres. De plus, les mesures propres au site pour faire face aux répercussions négatives sont habituellement contenues dans les conditions de permis particulières de chaque installation aquacole. Cette complexité existe pour trois raisons principales. Premièrement, la diversité même du secteur aquacole en ce qui concerne: (a) les espèces cultivées; (b) l'habitat dans lequel l'aquaculture est pratiquée; (c) le type de technologie utilisée et; (d) l'échelle de la production. Différentes règles juridiques peuvent généralement s'appliquer en fonction de chacun de ces facteurs. Deuxièmement, en dehors de la législation qui a pour objectif spécifique l'aquaculture, l'aquaculture se déroule à l'intérieur et est soumise aux règles d'un cadre juridique beaucoup plus large qui traite de diverses questions telles que la planification et le développement de l'utilisation des terres, la gestion des zones côtières, l'emploi et les questions de santé et de sécurité et bien d'autres. Enfin, contrairement à la pêche marine de capture, l'aquaculture n'est pas une compétence exclusive de l'UE.

La révision de la réglementation de l'UE et des États membres démontre que le cadre existant vise à réglementer les impacts conformément aux meilleures pratiques. En outre, il démontre que, d'une manière générale, le cadre réglementaire est très efficace pour atténuer bon nombre des incidences environnementales et sociales négatives de l'aquaculture dans l'UE en partie, sinon en totalité, dans certains cas. Cependant, il y a des domaines émergents dans lesquels il est possible de renforcer ou de développer davantage le cadre réglementaire. Des préoccupations particulières subsistent en ce qui concerne la réglementation des impacts sur le bien-être des animaux (au-delà des contrôles de la densité de peuplement et des maladies/parasites) et du cadre entourant l'aquaculture des macro- et microalgues.

L'aquaculture est une pratique établie en Europe. Bien que certaines préoccupations subsistent au sujet des répercussions négatives sur l'ensemble des systèmes de production, les répercussions positives découlant de l'aquaculture et du cadre réglementaire global qui l'entoure doivent être reconnues. Toutefois, si le secteur aquacole de l'UE est en mesure de réaliser une nouvelle croissance, la vigilance doit être maintenue par la poursuite de la recherche, de la surveillance, de l'innovation technologique et de l'atténuation afin de contrer les répercussions négatives émergentes ou existantes, soutenue par un cadre réglementaire qui encourage le développement de processus de production à faible impact pour les poissons, les bivalves et les algues. Parallèlement à cela, étant donné que la perception du public a de l'aquaculture ne correspond pas aux preuves existantes, une communication ouverte et transparente autour de l'aquaculture devrait être considérée comme une priorité pour dissiper les « mythes » tout en étant honnête sur les pièges qu'elle représente. Divers impacts positifs sont actuellement étudiés dans le contexte des services écosystémiques, qui doivent être développés et contextualisés pour améliorer et faciliter davantage les avantages et la perception sociale.

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1 INTRODUCTION

On a global level, aquaculture is one of the fastest-growing industries, showing a 6 % annual increase since 2010. Due to limitations on wild capture fisheries production, aquaculture will need to further increase in order to help meet a growing demand for food production. By comparison, European Union (EU) aquaculture has yet to show the same rate of increase as other parts of the world, providing a potential area of growth and further development. For example, while aquaculture production in the EU increased by 24 % since 1994, it has only grown 6 % since 2007. EU wild capture fisheries production has shown a decreasing trend between 1990 and 2018. Consequently, aquaculture has become relatively more important to the supply of seafood, reaching 1.2 million tonnes valued at EUR 4.1 billion in 2018 (STECF-20-12). In 2018, the aquaculture sector provided around 20 % of the fish and shellfish supply within the EU. European aquaculture is stimulated via innovation programmes and guidelines (EC, 2021) to support, stimulate and develop the capacity and sustainability of production.

Plant-based and animal food from the world's oceans is receiving more attention from a nutritional perspective and with respect to its environmental footprint (Troell *et al*., 2014; Gentry, 2020). Although insights into the world's aquatic production capacity and transition pathways vary, there is consensus on the vital role of aquaculture in food production (van der Meer, 2020). However, aquaculture is a complex domain: production dynamics, value chains and socio-economic effects differ greatly throughout production systems, geography and social context.

Aquaculture production is associated with impacts, whether positive or negative and changes in the socio-economic system occur when practising any type of aquaculture.The impacts/changes also differ greatly between production type, geography and biophysical context. In addition, people's opinions on aquaculture impact are influenced by the social context, as well as their role within or outwith the sector, their background, experience, and knowledge base. Hence, a well-informed debate on the overall impact of aquaculture is required.

The overall purpose of this study is to clarify the scientific basis of the positive and negative impacts of European aquaculture from an economic, environmental and social point of view, in order to facilitate a well-informed debate. The study is therefore based on scientific evidence, not on public opinions.

2 METHODOLOGY

This study adopted a collaborative approach between two Specific Contracts under both Lots of the Framework Contract EAME/EMFF/2018/011. This enabled a common methodology to be applied across the European Union: Lot 1 (Baltic Sea and North Sea) and Lot 2 (Atlantic EU Western Waters and the EU Outermost Regions). The Mediterranean Sea and Black Sea region was included as part of the geographic scope.

Work was undertaken within six main tasks as highlighted in Figure 1. A detailed methodology is presented in Annex 1.

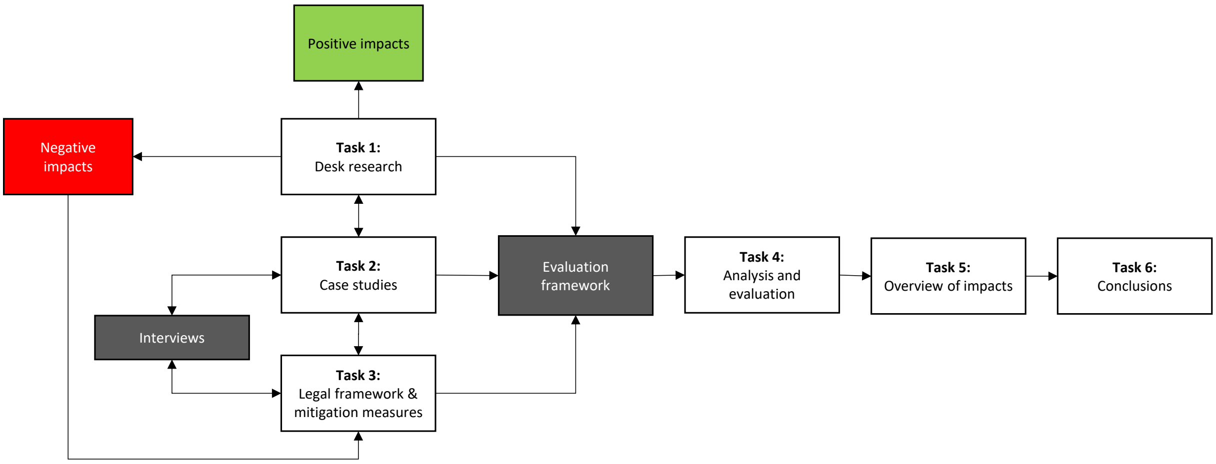

Figure 1: Schematic diagram showing interaction between tasks during implementation

Task 1: Desk research to collect state-of-the-art scientific information. The project team started with extensive desk research to collect state-of-the-art scientific information related to the possible positive and negative impacts of aquaculture activities from economic, environmental and social perspectives. The reviews addressed the following aquaculture systems: finfish cage culture; ponds, tanks and raceways (PTRs); recirculating aquaculture systems (RASs); macroalgae; and microalgae. Scientific literature was reviewed from sources mainly within the EU, but included associated countries (Iceland and Norway), the UK, the USA and other important aquaculture producers. This approach was taken to ensure that impacts which may be relevant to the EU but which may simply have received little attention thus far were not overlooked.

The literature reviews from Task 1 can be found in Annex 2 of this report.

Task 2: A deep analysis of impacts was undertaken for a series of case studies, drawing on: the scientific literature from Task 1; supplementary scientific and grey literature[1] reviewed by case study authors which was of specific relevance to the case study; and key expert interviews. Case studies were used to verify impacts identified in the scientific literature, to identify any impacts potentially overlooked by the scientific literature, and to identify legislation and mitigation relevant to the aquaculture type at the national level. Key experts consulted were those from national authorities and national research institutes in countries where case studies were conducted, as well as some industry members of the Aquaculture Advisory Council (speaking in a personal capacity) who addressed impacts across the EU rather than at the case study level. An in-depth analysis of the most important and most broadly identified impacts was carried out through a series of case studies across the EU under both Lots (Table 1). The selection of case studies took into consideration the specificities of the different

[1] Grey literature, materials and research produced by organizations outside of academic publishing and distribution channels. Common grey literature publication types include reports, working papers, government documents, white papers and evaluations.

aquaculture environments (marine, freshwater), locations (land-based, sea-based), cultivation techniques (sea cages, PTRs, RASs, integrated multitrophic aquaculture (IMTA), ropes, trays etc.) and target species (fish, bivalves, and algae). Various EU Member States were selected for each case study under Lot 1 (Denmark, Germany, France (performed in a literature quick scan without key expert consultation), Poland, Netherlands) and Lot 2 (Croatia, Greece, Ireland, Italy, Portugal, Spain).

Table 1: Case studies and countries evaluated in this study. France is performed in a literature quick scan without key expert consultation),

Production system; species	Country	Lot number
Shellfish: mussel production	Netherlands	1
Shellfish: oyster trays	France	1
Shellfish: oyster ponds or tray different site	France	1
Macroalgae (culture, with respect to other countries as reference)	France	1
Ponds, tanks and raceways: carp	Poland	1
Ponds, tanks and raceways: carp	Germany	1
Ponds, tanks and raceways: trout	Germany	1
Recirculating aquaculture systems: trout	Denmark	1
Microalgae	Germany	1
Finfish sea cages: sea bream, sea bass	Greece	2
Finfish sea cages: sea bream, sea bass	Croatia	2
Sea cages: Atlantic salmon	Ireland	2
Shellfish: Mediterranean mussels (*Mytilus galloprovincialis*)	Spain	2
Shellfish: blue mussels (*Mytilus edulis*) (rope grown)	Ireland	2
Shellfish: clams, oysters	Portugal	2
Macroalgae	Spain	2
Microalgae	Greece	2
Ponds, tanks and raceways: trout	Italy	2
Recirculating aquaculture systems: sole	Portugal	2
IMTA: comprising separate activities	Portugal	1 & 2

Scientific literature collected under Task 1 was filtered by topic to provide a baseline of positive and negative impacts for each case study. Additional sources of information were reviewed for each case study, including grey literature and relevant datasets. To complement the results of the desk research, key experts from various national administrations and the Aquaculture Advisory Council were consulted using a semi-structured interview approach. Interview guidelines (Annex 1) addressed overarching and case-study-specific aspects of aquaculture to verify existing information and identify new or previously unidentified impacts. The study aimed to provide robust conclusions underpinned by rigorous scientific literature and not public perceptions or opinions. For this reason, consultations were limited in scope and did not represent the wider civil society, including non-government organisations (NGOs).

An overview of results from the desk research showing main environmental, economic and social impacts are presented in Section 3.1. To complement the scientific literature, a summary of the main findings from the key expert consultations are presented in Section 3.2.1. Both sets of results are compared in Section 4.1.

The case study reports from Task 2 can be found in Annex 3 of this report.

Task 3: Review regulatory framework and mitigation measures. In parallel with Task 2, the regulatory framework was reviewed in each case study along with mitigation measures implemented (where feasible) for the existing negative impacts. The regulatory review for each case study is contained in Annex 3. The approach of the regulatory measures adopted at EU and Member State level to the mitigation of negative impacts from aquaculture is summarised in Section 5 along with a preliminary analysis of the extent to which the regulatory framework mitigates negative impacts from aquaculture, based on the case studies and expert interviews.

The case study reports from Task 3 can be found in Annex 3 of this report.

Tasks 4 and 5: Analysis of impacts and overview of evaluation. All scientific information and the results of the interviews from Tasks 1–3 were analysed and evaluated to provide a detailed overview of the main positive and negative impacts for different aquaculture types. The results, shown in Section 4, include a series of tables for each aquaculture type.

Task 6: Conclusions. A set of clear and explicit conclusions based on the analyses and evaluations are presented in Section 6.

Whilst the approach taken in this study seeks to provide a thorough and cohesive overview of the impacts from aquaculture in the EU there are a some limitations to the scope of the work which must be acknowledged. Specifically, this study does not seek to:

- Assess the magnitude or occurrence probability of those impacts identified. Instead impact is measured in terms of the frequency of references to impacts in the reviewed scientific literature and their relative importance in the opinion of key experts;
- Compare the magnitude or occurrence probability of impacts among different types of aquaculture, technologies are considered in isolation;
- Compare the impacts identified to those of alternative farming of plants and animals (e.g., terrestrial livestock).

3 OVERVIEW OF IMPACTS

The following discussion draws on metadata for the impacts of aquaculture collected from the following sources:

- Desk research (Task 1, Annex 2);
- Socio-economic indicators derived from the Scientific, Technical and Economic Committee for Fisheries (STECF) - The EU Aquaculture Sector – Economic report 2020 (STECF-20-12); and
- Key expert consultations that underlie the case studies (Task 2, Annex 3).

3.1 Desk research

The desk research sought to identify the impacts of aquaculture as seen in the scientific literature. While the research was focussed primarily on Europe and the EU, literature from other parts of the world were included in the review so as to not overlook impacts which may be relevant to the EU but which may simply have received little attention thus far. Similarly, because the main producers using specific technology/taxa combinations may not be within the EU (e.g., Norwegian and Scottish Atlantic Salmon), but the same technology/taxa combinations may also exist the EU (e.g., Irish Atlantic Salmon), it is important to consider the impacts seen elsewhere. In total >7 000 pieces of literature were identified, which was narrowed down to around 1 500 pieces after screening. In total 537 pieces of scientific literature were tagged and used in the final desk reviews.

3.1.1 Environmental (scientific literature)

Aquaculture impacts identified by the tagging procedure in Task 1 (Figure 2, Figure 3) are predominantly environmental in nature, this is likely a result of the search parameters used in the scientific literature review, the interests of the academic sector, and the interests of research funding institutions. The metadata shows clearly that finfish aquaculture has received the greatest attention in the scientific literature (56.0 %), followed by shellfish (30.2 %), with algae (both macroalgae and microalgae) receiving the least (13.8 %). Algal culture at commercial scale is relatively new in the EU and, in the case of microalgae, often restricted to laboratory environments. It is therefore unsurprising that algal aquaculture has received relatively little attention. Despite shellfish culture having been established for longer than finfish culture, it has received less academic attention in the last ten years, possibly a reflection of its comparatively smaller value and lower level of perceived and/or potential environmental impact.

The finfish scientific literature is dominated by studies focusing on or demonstrating negative impacts (such scientific literature comprises 70.6 % of the total). The primary negative impacts are for species and habitat conservation (e.g., from genetic introgression of escaped fish, transmission of disease and parasites to wild fish), discharge of effluents (either solid or dissolved), and subsequent nutrient enrichment in the benthos (i.e., benthic enrichment). Positive impacts in finfish scientific literature focus primarily on effluent discharge, specifically the positive impacts of recirculating aquaculture systems (RASs) in reducing levels of effluent discharge seen from other technologies, and for habitat and species conservation through reduction of pressure of wild stocks.

The shellfish scientific literature related to bivalves is balanced between studies focusing on or demonstrating positive (56.0 %) and negative impacts (44.0 %). The primary negative impacts are on benthic enrichment through solid waste deposition (including shells) and for species and habitat conservation (e.g., from seed harvest and potential spread of invasive species in the event of translocation). Positive impacts in shellfish scientific literature focus primarily on the potential for shellfish culture to improve water quality (e.g., reducing eutrophication and nitrogen fixation) and for habitat and species conservation through reduction of pressure of wild stocks. The algal scientific literature is dominated by studies focusing on or demonstrating positive impacts (87.5 %). The positive impacts are primarily climate related (e.g., carbon capture and counteracting ocean acidification) and implication for biogeochemical cycles (nutrient bioremediation and nitrogen fixation).

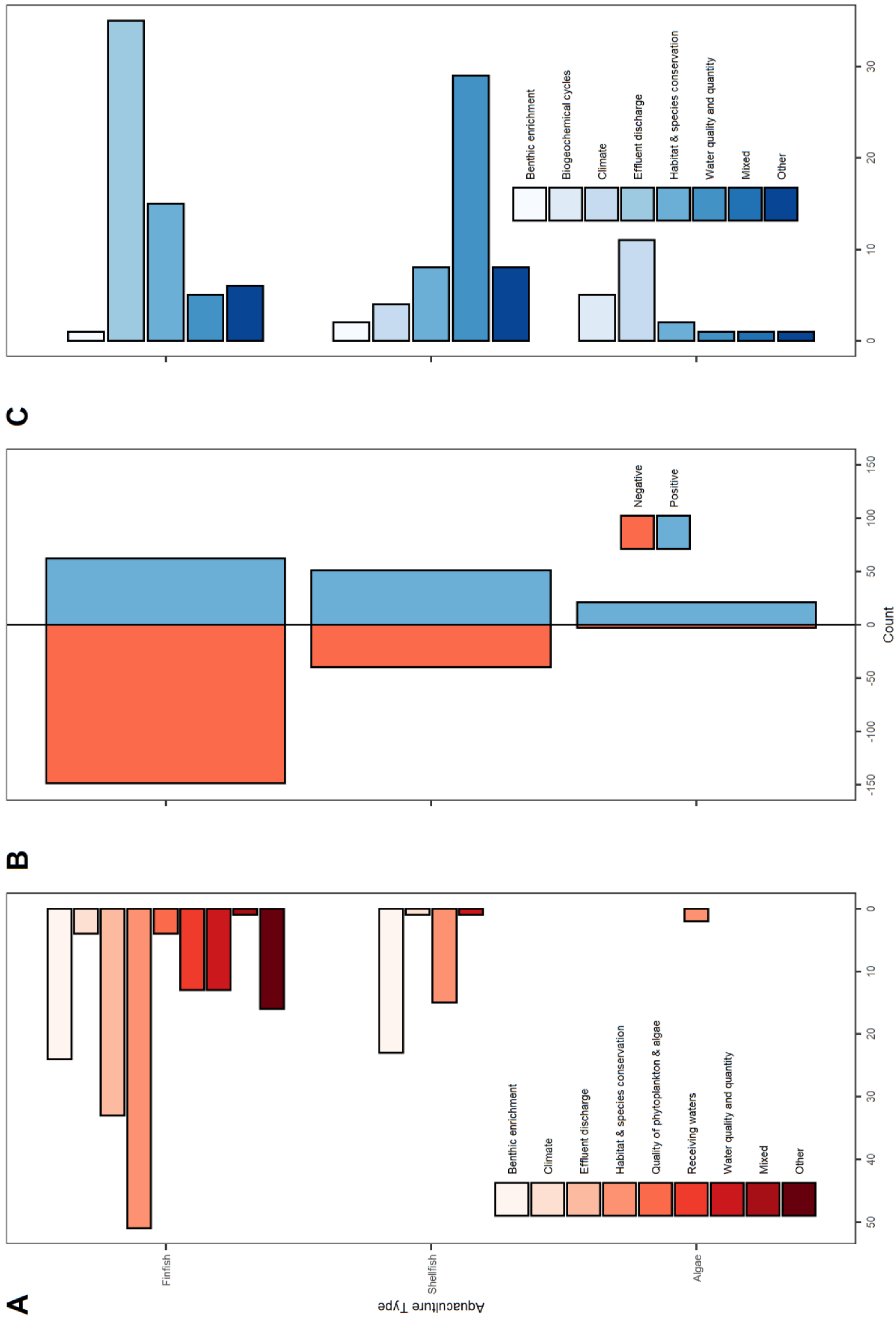

Figure 2: Volume of scientific literature addressing broad aquaculture impacts, broken down by taxonomic classification (B) and category of positive (C) and negative (A) impact types, as identified through the tagging of scientific literature used in the Task 1 reviews

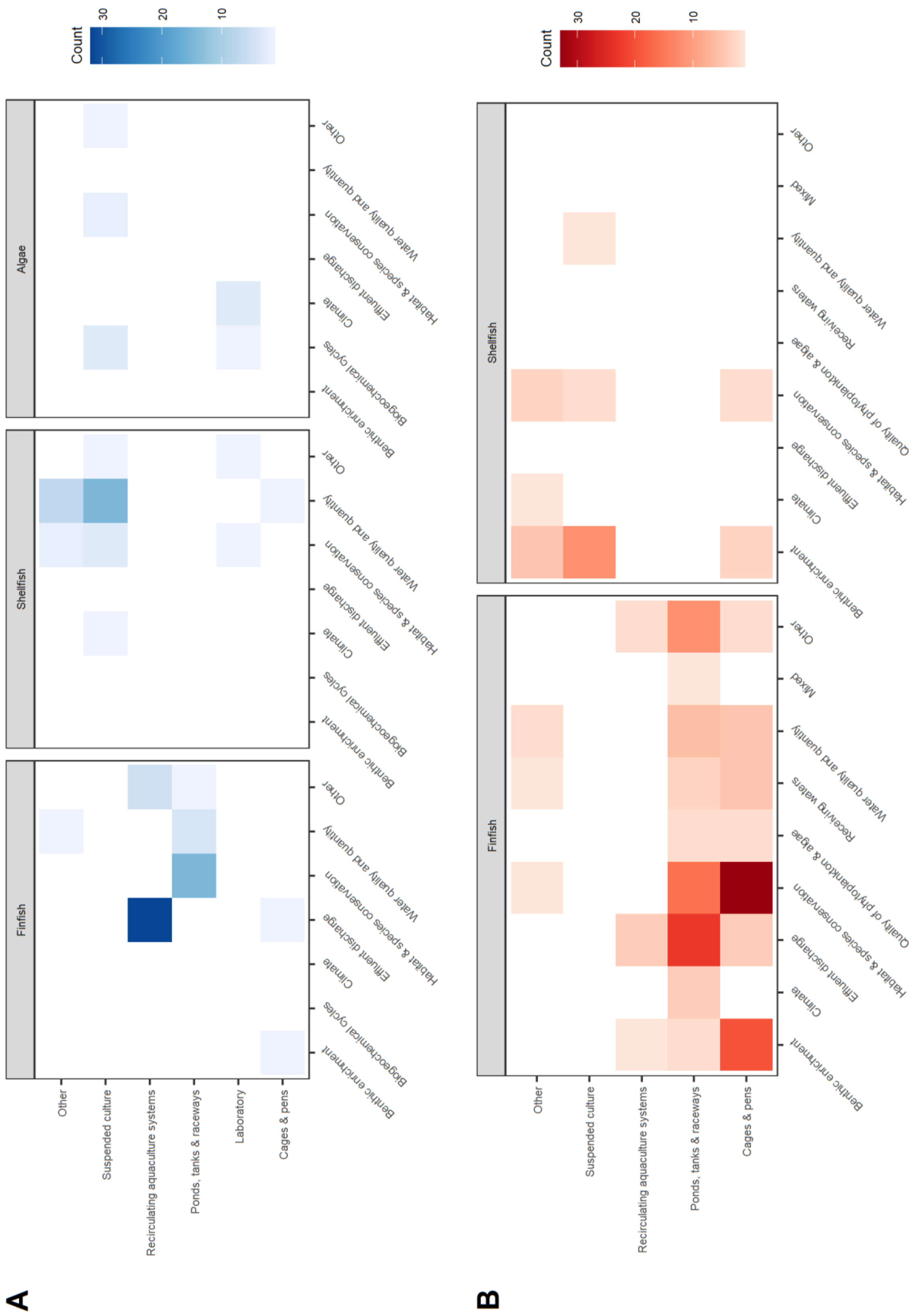

Figure 3: Volume of scientific literature addressing broad aquaculture positive (A) and negative (B) impacts, broken down by taxonomic classification and technology classification, as identified through the tagging of scientific literature used in the Task 1 reviews

There is strong geographic variability in the source of scientific literature across aquaculture taxonomy and technology type (Figure 4, Figure 5). The finfish scientific literature is predominantly from Norway (sea cages), Denmark (RAS), and Poland and Czech Republic (PTRs). The shellfish scientific literature is predominantly from the USA, Europe, and Canada (various culture types). The algae scientific literature is predominantly from China (sea cages), Denmark (RAS), and Poland and Czech Republic (PTRs).

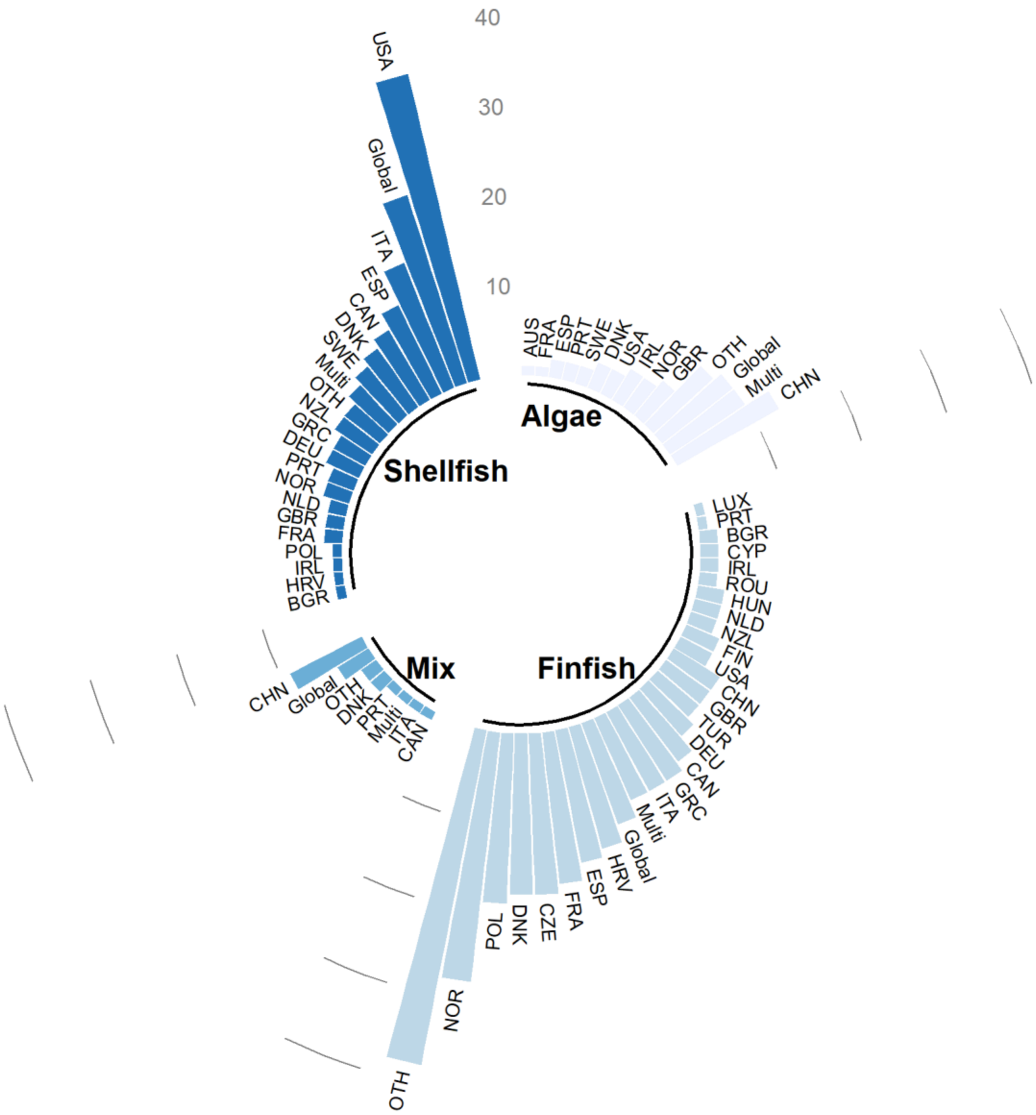

Figure 4: Geographic (ISO Alpha-3 codes) focus of the aquaculture scientific literature by broad taxonomic classification

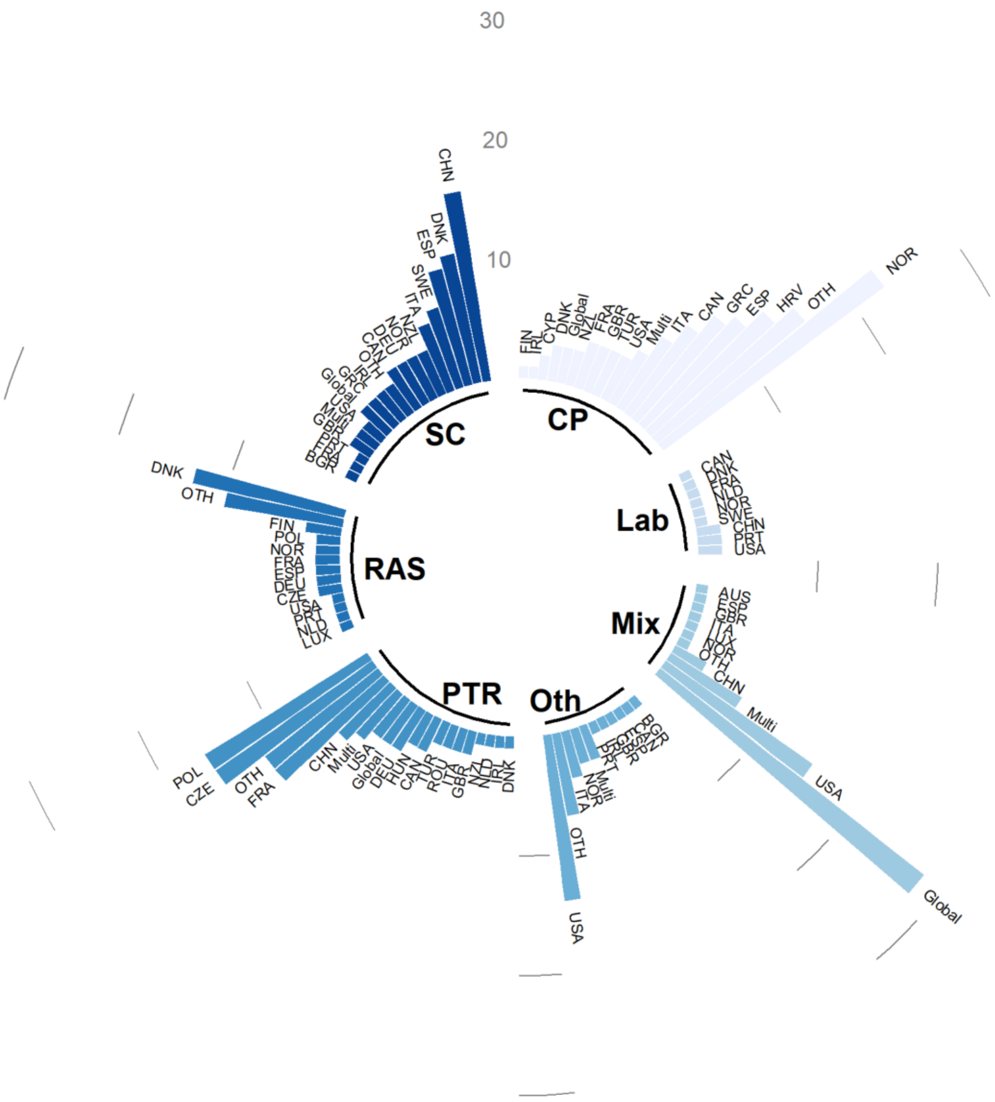

Figure 5: Technological focus of aquaculture scientific literature by broad technology classification. *CP = cages or pens, SC = suspended culture (e.g., longlines), Lab = laboratory, RAS = recirculating aquaculture systems, PTR = ponds, tanks and raceways, Mix = mixture of technologies, Oth = other technologies.*

3.1.2 Economic (scientific literature)

In Task 1, the most recent data from the STECF 20-12 was reviewed, with the most recent year contained being 2018, alongside data from the scientific literature ranging from year of publication (2010–2021). STECF data is the most complete data set, covering all Member States. An additional literature search was conducted on specific indicators (see Annex 1.1) but only a limited number of relevant publications were retrieved.

Aquaculture is one of the fastest-growing food-producing sectors in the world and is an increasingly important contributor to global food supply and economic growth. According to the latest worldwide statistics on aquaculture compiled by FAO, world aquaculture production attained 114.5 million tonnes in live weight in 2018[2]. The share of global

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[2] FAO report, 2020 on ‘The state of global fisheries and aquaculture’.

supply for human consumption from aquaculture increased from 16 % in 1990 to 54 % in 2018. The production from world capture fisheries has been fluctuating around 90 million tonnes per year during the last two decades. In contrast, global aquaculture production has been increasing steadily (**Error! Reference source not found.**).

Figure 6: World and EU-27 seafood production (capture and aquaculture): 1990-2018 Source: FAO, 2020.

The global value of aquaculture production reached EUR 219 billion in 2018 (FAO, 2020). The sector has increased production more than four times since 1990. However, this growth has been driven primarily by Asian countries, which produce 92 % of the world's aquaculture products. China is the most important producer of aquaculture products in the world, producing 58 % of global aquaculture products. EU aquaculture production represented only 1.0 % of the world production in terms of weight and 1.5 % in value.

The aquaculture production in EU has increased by 24 % since 1990; however, since 2007, the production has increased by only 6 %. As EU capture fisheries production has shown a decreasing trend from 1990 to 2018, aquaculture has become relatively more important to supply the seafood market, reaching 1.2 million tonnes valued at EUR 4.1 billion in 2018 (Data Collection Framework, DCF; and expert working group, EWG estimates). In 2018, the aquaculture sector provided around 20 % of the fish and shellfish supply in EU (Figure 6).

EU (not including the UK or Norway) aquaculture production is mainly concentrated in four countries: Spain, France, Italy and Greece (Figure 7). These four countries account for 69 % of the total EU aquaculture production volume. In terms of value, France is the largest contributor in EU with 21 % of the total turnover, followed by Spain (18 %), Greece (14 %) and Italy (9 %). These five countries combine 62 % of the total EU aquaculture turnover (Table 2).

The total nominal turnover from the EU aquaculture sector was EUR 3.9 billion and EUR 4.1 billion in 2017 and 2018, respectively (Figure 8). This represents a 7 % increase from 2017 to 2018, while the increase from 2016 to 2018 is 11 % over the two years. A driver to the increase in turnover since 2013 is related to a general rise in prices. The increasing prices together with the increase in the overall production in the EU aquaculture sector contribute to the increase in turnover from 2013 to 2018. The majority of the turnover at the EU level comes from marine finfish production (45 %), while shellfish production accounts for 31 % and freshwater finfish production 25 %. The total number of aquaculture enterprises has remained relatively stable at around 15 000 between 2008 and 2018. However, the number of shellfish enterprises has declined slightly across the period, with the number of freshwater finfish enterprises rising simultaneously.

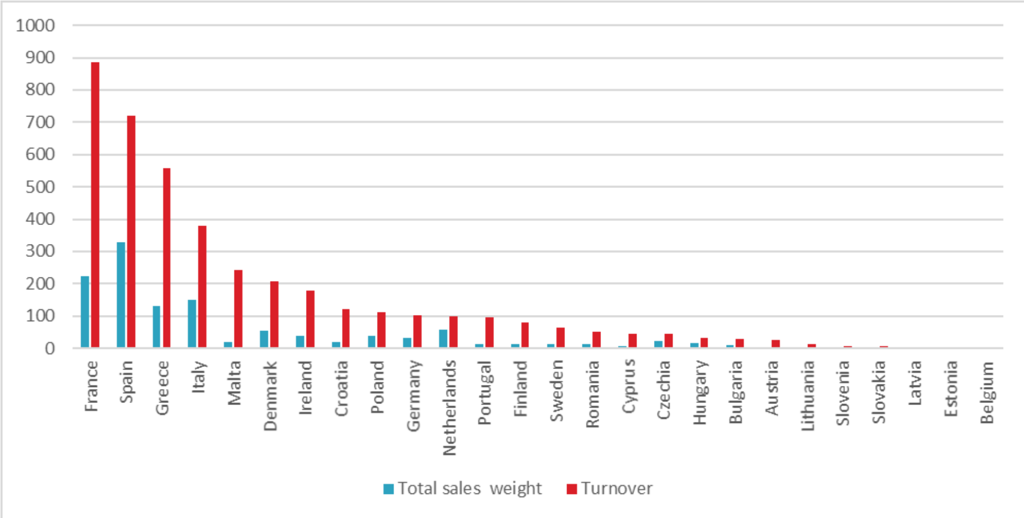

Figure 7: Total sales weight (in thousand tonnes) and turnover (in million EUR) in the EU aquaculture sector: 2018. Source: EU Member State data submission and EWG estimates, 2021.

Table 2: Total economic indicators for the EU aquaculture sector in 2018. Source: EU Member State data submission and EWG estimates, 2021.

Country	Gross sales total turnover*	Gross value added*	Net profit*	Estimated enterprises*	Wages and salaries*	Average company revenue*
Austria	26.4	-	-	85	-	0.3
Belgium	0.8	-	-	2	-	0.4
Bulgaria	25.6	13.5	7.4	627	3.5	0.0
Croatia	122.6	59.2	27.9	161	17.7	0.8
Cyprus	45.3	-	-	16	-	2.8
Czechia	45.2	-	-	150	-	0.3
Denmark	176.6	55.6	12.0	99	31.1	1.8
Estonia	2.0	-	-	10	-	0.2
Finland	72.1	21.6	2.3	157	13.2	0.5
France	888.1	457.6	118.5	2 782	247.6	0.3
Germany	150.2	84.5	7.6	490	69.3	0.3
Greece	597.9	61.9	52.4	650	61.5	0.9
Hungary	38.4	-	-	120	-	0.3
Ireland	189.1	60.9	19.2	289	31.8	0.7
Italy	610.1	216.7	126.2	711	74.6	0.9
Latvia	5.4	1.4	-1.1	85	2.4	0.1
Lithuania	12.5	-	-	47	-	0.3
Malta	305.0	15.1	2.3	7	8.6	43.6
Netherlands	57.3	29.9	9.3	70	14.3	0.8
Poland	121.1	-	-	1 242	-	0.1
Portugal	88.2	68.9	47.6	846	14.7	0.1
Romania	30.5	13.8	-0.2	430	11.4	0.1

Country	Gross sales total turnover*	Gross value added*	Net profit*	Estimated enterprises*	Wages and salaries*	Average company revenue*
Slovakia	5.5	-	-	19	7.2	0.3
Slovenia	1.1	0.1	-1.3	7	0.5	0.2
Spain	625.4	224.0	1.9	2 895	198.4	0.2
Sweden	48.2	34.7	21.1	93	9.6	0.5
Total EU	4 290.5	1 704.9	-	12 389	-	0.4
United Kingdom	1 098.9	294.3	111.4	270	118.2	4.1
Norway	6 784.4	-	-	426	-	-
***All monetary values are in million EUR.**						

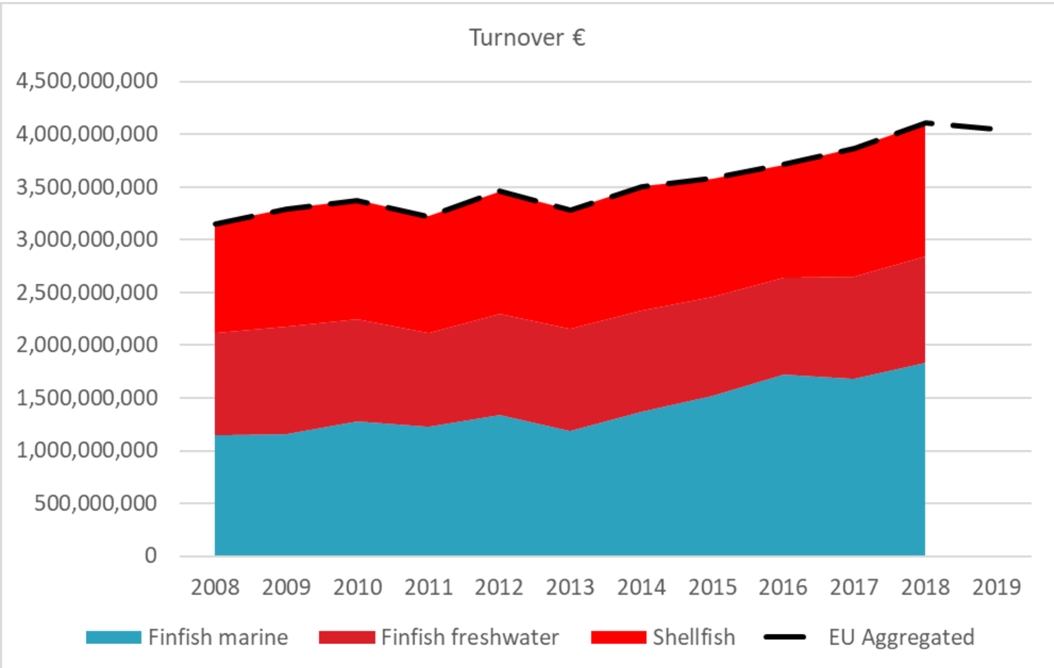

Figure 8: Aquaculture turnover in nominal and real values at EU-28 level, 2008-2019. Source: EU Member State data submission and EWG estimates, 2021.

3.1.3 Social (scientific literature)

In Task 1, the most recent data from the STECF 20-12 was reviewed, with the most recent year contained being 2018, alongside data from the scientific literature ranging from year of publication (2010–2021). STECF data is the most complete data set, covering all Member States. An additional literature search was conducted on specific indicators (see Annex 1.1) but only a limited number of relevant publications were retrieved.

From an employment perspective, the social importance of the aquaculture sector is not always reflected in its contribution to EU aquaculture. Total employment in the EU-27 aquaculture sector, including estimates for the Member States not reporting data, was around 69 000 persons in 2018 and represents a decrease from around 80 000 in 2009. Despite its lower overall value, the shellfish sector accounted for around 53 % of employment, freshwater finfish production employed 35 % and marine finfish production 13%. Shellfish production employs more labour compared to marine and freshwater production. The shellfish sector most often comprises small family-owned businesses and has large social importance in some regions in the EU. Shellfish production is often concentrated to a few local communities in the EU. According to the EUMOFA map of first sales[3] the shellfish employment dependent regions are for instance Galicia and specific coastal villages in Portugal, France, Italy, Netherlands and Denmark.

Overall, it is estimated that full-time-equivalent (FTE) employment in the EU-27 amounted to 40 200 and 39 900 in 2017 and 2018, respectively, corresponding to a 2 % decrease. The EU aquaculture sector has a significant component of part-time work. This can be seen from the ratio of FTEs to total employees (Table 3). The estimated data shows that the ratio for the EU aquaculture sector was 0.60 in 2017 and 0.57 in 2018. This is at the same level as the previous report. The falling ratio may be seen in combination with the higher contribution in volume and value from the mussel sector, because a large proportion of part-time and seasonal employment in the aquaculture sector originates from the shellfish segments.

Table 3: Total social indicators for the EU aquaculture sector in 2018

Country	Sales volume (tonnes)	Total employment (persons)	Total employment (FTE)	FTE female	FTE male
Austria	3 991	374	186	-	-
Belgium	111	10	48	-	-
Bulgaria	9 848	1 159	1 023	115	876
Croatia	19 741	2 334	1 730	-	-
Cyprus	7 438	462	406	-	-
Czechia	21 751	1 615	901		
Denmark	48 355	537	358	-	-
Estonia	504	40	33	-	-
Finland	12 301	506	348	71	249
France	245 729	16 265	9 535	-	-
Germany	33 585	2 136	1 254	-	-
Greece	144 721	3 832	3 524	424	3 254
Hungary	17 852	2 321	877	-	-
Ireland	40 356	2 086	1 099	-	-
Italy	182 962	5 456	3 287	-	-
Latvia	1 570	245	166	-	-
Lithuania	3 750	506	220	-	-
Malta	22 537	332	283	-	-
Netherlands	47 472	195	201	-	-
Poland	43 361	8 731	3 459	-	-
Portugal	12 339	2 942	921	154	639
Romania	12 182	3 252	2 560	-	-
Slovakia	2 224	1 042	698	-	-

[3] https://www.eumofa.eu/map-of-eu-first-sales

Country	Sales volume (tonnes)	Total employment (persons)	Total employment (FTE)	FTE female	FTE male
Slovenia	702	22	22	-	-
Spain	361 724	17 794	6 528	-	-
Sweden	12 328	443	267	36	246
Total EU	1 309 434	74 634	39 931		
United Kingdom	189 900	3 302	2 833	-	-
Norway	1 354 941	8 548	6 190	952	5 238

The average wage is calculated as the sum of the costs in wages and salaries and the imputed value of unpaid labour divided by the total number of FTEs. DCF data from 19 countries show that the average wage per FTE for the EU aquaculture sector in 2018 was about EUR 25 700 per year. This is an increase of 11 % from the EUR 23 200 reported in 2017.

Male workers make up 76 % of employees in the aquaculture sector, with 23 % female and 1 % reported as unknown. Seventeen countries provided data for the gender variable. The percentage of female employees in the different Member States varied between 0 % in the Netherlands and up to 38 % in Germany. Only France used the option 'unknown'; however, the overall percentage is minor (3.4 %).

Relative to fisheries and the fish-processing sector, the aquaculture sector employs younger workers. In aquaculture, the 40–64 age class makes up the largest proportion (43.4 %, relative to 58 % of fisheries and fish-processing) of people employed, followed by the 25–39 age class (27.5 %). A further 7 % were apportioned to the 15–24 age class, 2.2 % to the over-65-year category, 0.1 % to the 14 or under age category and 19.8 % were unknown. The percentage in the 40–64 age group is highest in Slovenia (81.5 %), Bulgaria (68.2 %) and Latvia (66.1 %). More than 59 % of the employees in the Netherlands were in the 25–39 age group, followed by 50.8 % in Malta and 40.1 % in Croatia. The highest percentage of employees aged over 65 years is in Portugal and Sweden: 15.6 % and 10.9 %, respectively (Figure 9).

The aquaculture sector is potentially an important source of employment for low-skilled national workers, particularly in rural areas. Of people employed in the EU aquaculture sector, 39.9 % and 31.6 % had a low or medium level of education, respectively (Figure 10). Ireland provided the distribution by education level but the classes do not correspond to data submitted by other Member States, so they were converted to be comparable with data from the other Member States. Spain (58 %), Portugal (47 %), Ireland (~44 %), and Denmark (44 %) have the highest proportions of low-education workers. Most of these low-skilled workers are likely to be nationals or EU nationals. The majority (83 %) of people employed in the EU aquaculture sector were nationals of their own country, followed by 2.7 % from non-EU / European Economic Area (EEA) nations, 2.6 % from the EU, 1.3 % from the EEA and 10.5 % of the employees had unknown nationality (Figure 11). In all the Member States, the national employees are the main employees. The proportion of nationals varied from 99.5 % in Bulgaria to 53.8 % in Greece. The other workers are mainly from EU Member States.

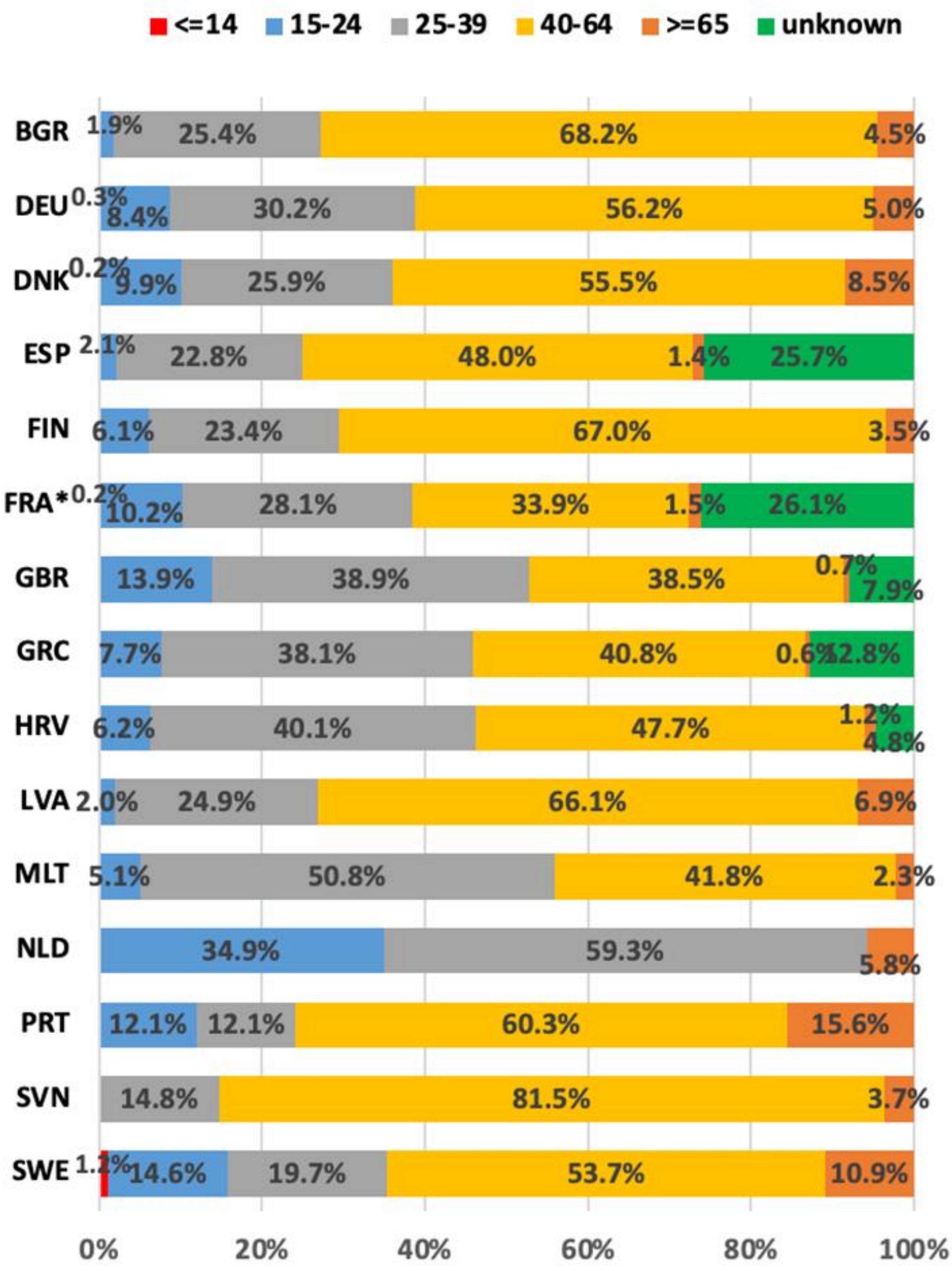

Figure 9: Age structure of the EU aquaculture sector. Source: EU Member State data submissions under the 2020 Aquaculture data call (Data Collection Framework) and elaboration by the expert working group. *Data is for 2018.

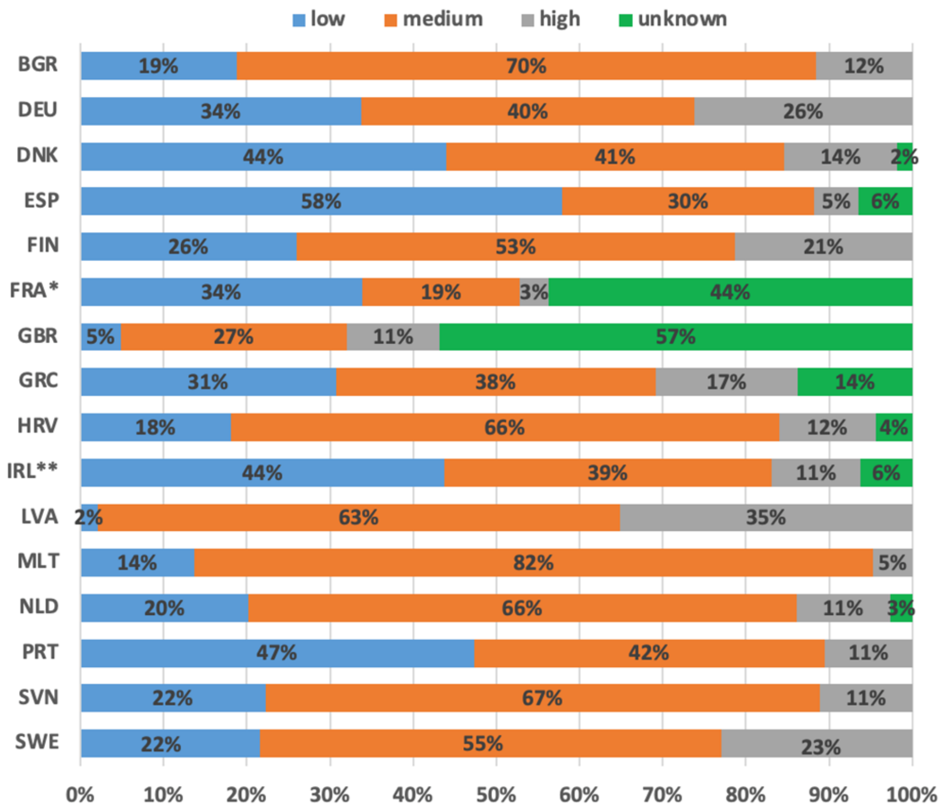

Figure 10: Education structure of the EU aquaculture sector. Source: Member State data submissions under the 2020 Aquaculture data call (Data Collection Framework), and elaboration by the EWG. Ireland provided education in different categories than agreed by the Planning Group on Economic Issues (PGECON), so the Irish data were converted as follows: PrimaryEd to Low; SecondaryEd to Medium; ThirdEd to High; and Other to Unknown.

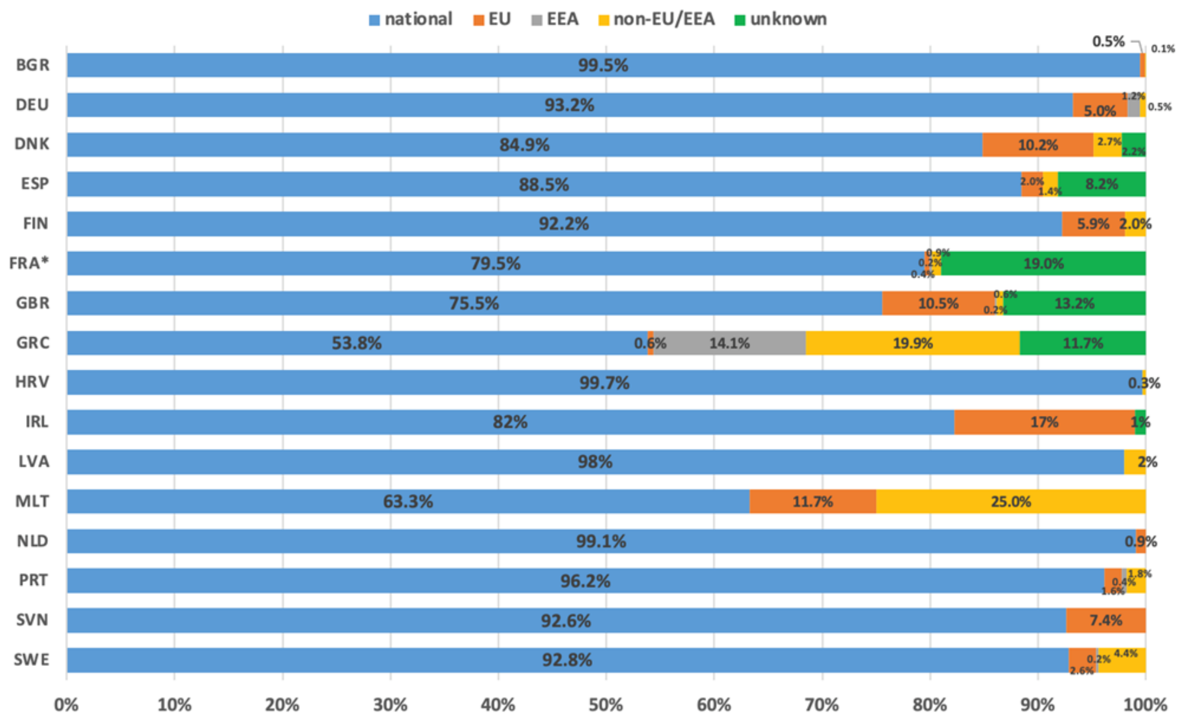

Figure 11: Nationality structure of the EU aquaculture sector. Source: Member State data submissions under the 2020 Aquaculture data call (Data Collection Framework), and elaboration by the EWG.

3.1.4 Summary of scientific literature reviews

To get a good overview of the relevant scientific literature on aquaculture in Europe, summaries of studies on finfish cage, finfish pond culture, finfish RAS, shellfish culture, macroalgae culture and microalgae culture are presented in this section.

3.1.4.1 Finfish sea cage

Cultivation of finfish in marine coastal waters predominantly employs moored enclosures, comprising a net or cage-like structure suspended from a floating platform; termed 'net pens' or 'sea cages'. Due to the exposure of the fish stock in net pens to the open environment, there are risks associated with pollutants and parasites for the fish stock, and direct emissions of production wastes to the open environment. Finfish aquaculture in net pens represents the bulk of European aquaculture production, having grown exponentially since the late 1980s. Effects related to the enhanced emissions of dissolved nutrients and particulate matter, as well as the interaction of fish stocks and parasite loads have been the most documented in terms of normal operations. Risks associated with intermittent events, such as storm-related damage to net pens and escape of domesticated fish into the wild, are also often cited. Sedimentation underneath and around finfish farms is the major consistent effect of feeding fish in sea cages. Natural recovery of sediments is variable; the industry practice of fallowing appears to permit some repeatable degree of recovery and stabilisation over long periods.

Escape of fish is well documented and potentially a major risk, but is an episodic hazard and not a consistent issue. The long-term consequences of escaping fish are largely unknown. Captured fish with hybrid genomes reveal that interbreeding of two conspecifics occurs, but the long-term consequences of genetic introgression are as yet unknown. The documentation on the effect of escaped fish interacting with other marine species is moderate and there is a need for more data collection.

Pelagic emissions (releases to the water column) of dissolved nutrients are generally not impactful at the ecosystem-scale, due to effective assimilation by the ecosystem and sufficient limitations of farm density in a given water body. The effect on enhancing or generating eutrophic conditions has been difficult to ascertain and is reliant on ambient biophysical conditions.

Antimicrobial resistance is potentially a very significant impact that reaches beyond aquaculture practices. Chemotherapeutants (e.g. pesticides) and other veterinary medical residues have repeatable local, farm-scale, effects on non-target species; however, population-level consequences (impact on the whole popultion rather than a single specimen or group) are not well documented.

Interactions with marine mammals and protected species vary over locations, but are generally benign provided best management practices are implemented.

3.1.4.2 Finfish ponds, tanks and raceways

In both carp and trout pond culture, effects found within the ponds do not necessarily impact the effluent waters. In carp ponds, water-retention times, water temperatures, production intensities, and other factors allow higher retention and biodegradation of nutrients and organic matter than seen in trout production.

The severity of other impacts is largely determined by the intensity of production. Carp production can vary between positive and negative effects on the environment in relation to nutrient emissions. Oxygen concentrations can be changed by the pond aquaculture, hazardous emissions can enter the receiving streams and biogeochemical processes can be affected or the turbidity of the water can be affected.

In some cases, nitrogen, phosphorous and organic matter emissions from trout pond aquaculture were found to be significant but only for limited distances from the farm. However, trout farms increase biochemical and chemical oxygen levels of receiving streams, in most cases significantly, in waters up to 12 kilometres from the pond. Carp production can decrease but also increase the oxygen levels of water, which is connected to the biodegradation and primary oxygen production in the ponds. The same was found for the biochemical and chemical oxygen demand of the effluents, which seem connected to the intensity of production.

However, emissions of nitrogen, phosphorous or organic matter were found have negligible impacts on eutrophication . Carp farms also have the potential to reduce concentrations of these chemicals between water inflow and outflow significantly. Some carp farms changed the pH value significantly while others had no effect. The direct effect on the receiving streams was not clear.

There are several major impacts from pond aquaculture are on biodiversity. In past centuries, carp and trout aquaculture has had a significant effect on biodiversity in Europe and continues to do so. Most commonly reared species are not native to European waters and when they escape from the ponds have a significant negative impact on native species. Reared fish also brought non-native parasites and disease to European waters, which further affected the native fish species. However, nursery ponds may have a significant positive effect on amphibian taxa, dragonflies, and aquatic vegetation, of which some are endangered species.

Pond production has the potential to significantly increase the abundance of antibiotic-resistance genes in the receiving streams. Globally, pond aquaculture contributes to the significant greenhouse gas emissions resulting from production of feed and biodegradation of waste products. Pond dredging and aquaculture feed production can cause significant acidification, which is further compounds greenhouse gas emissions. Draining at harvest significantly increases suspended soils and nutrient loads of receiving streams. Dredging of carp ponds to remove sediments with heavy machinery causes the major share of emissions.

3.1.4.3 Finfish Recirculating Aquaculture Systems

RASs are confined, land-based systems that have largely developed as a means to control rearing conditions and mitigate environmental impacts associated with traditional aquaculture production. They are applied for producing both freshwater and saline species. RASs use significantly less water than traditional systems because they treat and reuse the water, and intensive RASs are decoupled from local waterways using bore/drainage water rather than surface water. Effluent treatment prior to discharge similarly minimises the impact on external environments, and there is no risk of escapees.

RASs have no major consistent or acute environmental effects, having largely been developed to mitigate environmental impacts associated with aquaculture. Hence, compared to traditional aquaculture farming, and with adequate management principles RASs:

- Use and discharge significantly less water, reducing the impact on local waterways;
- Can control rearing conditions enabling them to produce year-round under optimal conditions;
- Treat waste nutrients and effluents prior to discharge;
- Do not pose a risk to local populations from escapees; and
- Have elevated biosecurity and pathogen control.

However, RASs are expensive, complicated to operate, and can have a higher carbon footprint depending on energy source.

3.1.4.4 Shellfish culture

The cultivation of molluscan shellfish in Europe has been active for centuries, encompassing numerous species and cultivation techniques. Bivalve aquaculture is economically important, second only to finfish aquaculture. Production in Europe has stalled over the past decades, but notably has reduced from a peak in the late 1990s. Present in practically every marine region in Europe, the environmental contexts of production are broad. Bivalves fundamentally differ from their fed-animal counterparts in aquaculture production, as they are filter-feeding animals, and in general are produced by utilising the ambient seston in the water column and do not introduce feed inputs from external sources.

Bivalve farms have repeatedly been shown to concentrate particle immobilisation and deposition of organic matter, although the magnitude of deposition and associated effects is extremely variable. Regeneration of bioavailable nitrogen is a consistently reported effect of local organic deposition. However, this effect cannot be considered definitively negative or positive on the ecosystem-scale. The capture and harvest of organic matter, as well as enhanced denitrification are consistently reported effects that have a net benefit on the ecosystem-scale.

Improvement to water-quality indicators is potentially a major positive effect, but varies according to local conditions. The modification to food webs may influence recruitment of higher organisms (fish), but the combined top-down and bottom-up effects on planktonic organisms is poorly documented.

The transfer and introduction of shellfish between ecosystems has had a major environmental impact around Europe, fundamentally changing habitat structure and taxonomic composition in some areas as a result of primary and secondary species spread. Pathogen and parasite transfer has likewise been a major impact from insufficient biosecurity control.

Seed collection by dredging/fishing implies similar negative impacts on biodiversity and sediment habitat conditions as do typical fishing activities. The presence of bivalve farms generally appears to have positive effects on biodiversity, in particular, as a result of the introduction of hard substrate and functionality of the ‘reef effect’.

Reactive phosphorus regeneration may imply higher ecosystem productivity in phosphorus-limited environments; however, seasonal variability and unresolved fates provide uncertainty regarding the degree of this impact. Pelagic emissions of nutrients comprise a consistent minor effect, and are often difficult to measure.

Modifications to planktonic food webs, and the magnitude of these effects, are in general not considered consistently significant.

The impacts related to interactions with sea birds depends on whether the structure is submerged or emergent, as well as the conservation status of the bird.

3.1.4.5 Macroalgae culture

Macroalgae cultivation mainly takes place in marine coastal areas and requires deployment of seeded growth substrates, i.e., horizontally or vertically suspended ropes or nets attached to mooring lines fixed to bottom anchors. Associated positive environmental effects of seaweed farming derive from the fact that seaweeds are primary producers with no requirement for external input of feed, therapeutics or fertilisers, and are thus a net sink of CO_2 and inorganic nutrients from the marine environment (ecosystem services). Theoretically, environmentally negative effects of seaweed farming may result from change in hydrology and phytoplankton assemblage, enhanced benthic sedimentation and shading of the benthic habitat. However, the effects occur predominantly when farming is large scale and seaweed farming operations in Europe are still minor. Increasing the scale of seaweed farming could result in farms becoming hot spots for spreading non-native and pathogen species, habitat degradation from enhanced deposition of organic matter, genetic introgression in wild conspecifics, and loss of biodiversity. However, these affects are rarely seen in Europe.

At larger scale or when the density of operating farms is high, seaweed cultivation is expected to have positive impacts in eutrophic waters as a result of nutrient removal and prevention of harmful algal blooms at the local level. However, slowing of water currents, depletion of nutrients and reduction in solids resuspension within and around farms will likely influence phytoplankton species composition, abundance and their primary production, with unknown consequences.

To prevent the undesired spreading of organisms, marine spatial planning becomes increasingly important. Also, in selecting sites with sufficient water depth and flushing, long-term effects of shading benthic vegetation and loading of organic matter can be avoided.

3.1.4.6 Microalgae culture

Microalgae could play pivotal roles in remedying the energy, environment and food crises prevailing in the world. They can be cultivated in systems mainly classified into open, closed and hybrid, under autotrophic, heterotrophic or mixotrophic conditions. More than 40 species of microalgae have been isolated and analysed, and are cultivated as pure strains in intensive systems for use in aquaculture or for production of biomolecules for pharmaceutical and nutraceutical use and energy (biodiesel). Microalgae could use marginal land, thereby minimising competition with other food production.

Microalgae have been proved to be effective at recovering a range of compounds from wastewater, demonstrating a potential as a water clean-up method. Treatment of wastewater with microalgae could lead to bioaccumulation of excess nutrients and potentially toxic compounds including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), hormones, oils, etc. However, uncontrolled cultivation could lead to blooms, and disease or pests could result in population crashes, leading to loss of product and the need for clean-up operations.

Pond construction for cultivation could lead to the displacement of local fauna, destruction of habitats, land pollution, contamination, service expectancy reduction and effects on terrestrial diversity. Land design and planning with accurate first-hand data and scientific predictability is essential, and lack of such data would lead to risks, such as soil pollution, soil erosion, land-use overexpansion, increased pressure on farmland, and reduction in the efficiency of land use.

Microalgae offer a method for biofixation of carbon dioxide. CO_2 could be sequestered directly from the atmosphere and from flue gases, thereby providing a gas clean-up method. Biogenic emissions have been observed from microalgae. Research into the scale of these fluxes is in the early stages of development, but must be continued because these compounds are precursors to ozone destruction and low-level ozone formation. Location of cultivation sites should be assessed based on other local sources of emissions, as combinations of pollutants could lead to formation of secondary organic aerosols.

Microalgae production may have a detrimental effect on the local ecosystem, causing algal blooms and biological invasion.

Potential impacts on human and/or animal health may arise where microalgae are cultured in wastewater. Some bacterial species in wastewater may contain toxic components or release bio-toxins. The use of such algae as food or accidental release of such algae and subsequent consumption by wild or farmed animals could result in harmful biotoxin intake.

The cultivation of microalgae requires the addition of nutrients, primarily nitrogen, phosphorus, potassium and silicon (for diatoms). This requirement for additional chemical salts could become unsustainable as they are derived from fossil fuel resources. In addition, leakage of these salts could cause microalgae blooms.

The energy balance remains a hurdle for producing microalgae. Combining cultivation with wastewater and gases from industries will be essential for keeping energy inputs and prices low. However, their use as feed is questioned because of potential bioaccumulation of organic pollutants.

3.2 Case Studies

3.2.1 Key expert consultation (environmental, social, and economic)

A series of 18 case studies were undertaken (21 planned, 3 merged, 1 not undertaken) across different geographic regions, taxa and aquaculture technology types (Annex 3). A total of 40 semi-structured interviews (Annex 1) were conducted with key experts across the various case studies. Key experts consulted were those from national authorities and national research institutes in countries where case studies were conducted, as well as some industry members of the Aquaculture Advisory Council (speaking in a personal capacity) who addressed impacts across the EU rather than at the case study level.

The case studies collected Likert scale data (from 'very unimportant' −2, to 'very important' +2) on the perceived importance of a range of social and environmental impacts. The impacts considered were based on the 'Aquaculture Law Assessment and Revision Tool' (ALART) currently being developed by FAO. These impacts follow the logical order of aquaculture development starting from site approval through to post-production impacts. Respondents were also encouraged to add additional impacts they felt were of relevance where applicable. Mean weighted responses were collated by aquaculture categories in line with the Task 1 reviews. Weighting was conducted so that each case study made an equal contribution to the final result. Impacts that were scored by only one key expert or by no key experts across an aquaculture type were deemed irrelevant. The resultant mean-weighted values for positive and negative impacts of aquaculture (Figure 12, Figure 13) were used to assign a relative perceived importance of impacts of 'very important' (+1.01 - +2), 'important' (+0.01 - +1), or 'unimportant' (≤0). Impacts considered unimportant might result from the impact itself being considered negligible to begin with or being well controlled by existing legislation and regulation.

It is vital to note that key experts were asked only about the specific culture technology of each case study, and were not asked to make judgements relative to the impacts of other aquaculture technologies. As such, impacts considered as important in culture types generally considered fairly benign (e.g., RAS, macroalgae) may be relatively minor compared to the impacts of other culture technologies. Key expert responses for microalgae and Integrated multitrophic aquaculture (IMTA) were too few in number to be considered robust at this level of aggregation.

Positive impacts (Figure 12) identified across all aquaculture types included benefits for sector employment, rural economic development, market diversification, and consumer health, safety, and nutritional security. Positive impacts for water quality were perceived from all but cage and pen culture; reduced pressure on wild stocks for all but PTRs, and macroalgal culture; biodiversity enhancement for all but shellfish culture; and both recirculating aquaculture systems (because of the reduction relative to other finfish culture types) and macroalgae culture were considered positive influences on sedimentation.

As would be expected, negative impacts (Figure 13) varied widely among aquaculture types. From an aquaculture facility siting perspective, land-use impacts were broadly considered unimportant, with the exception of cage and pen culture. Impacts on coastal and maritime space use were considered an issue by key experts for *in situ*[4] shellfish and macroalgae culture, and cage and pen aquaculture. Shellfish and macroalgae culture were also considered to be of concern from a navigation perspective. There were also a range of concerns around aquaculture facility siting and its potential to affect sensitive biodiversity and habitats in the local area. In light of this, future focus on reducing spatial conflicts may be required for sectoral growth.

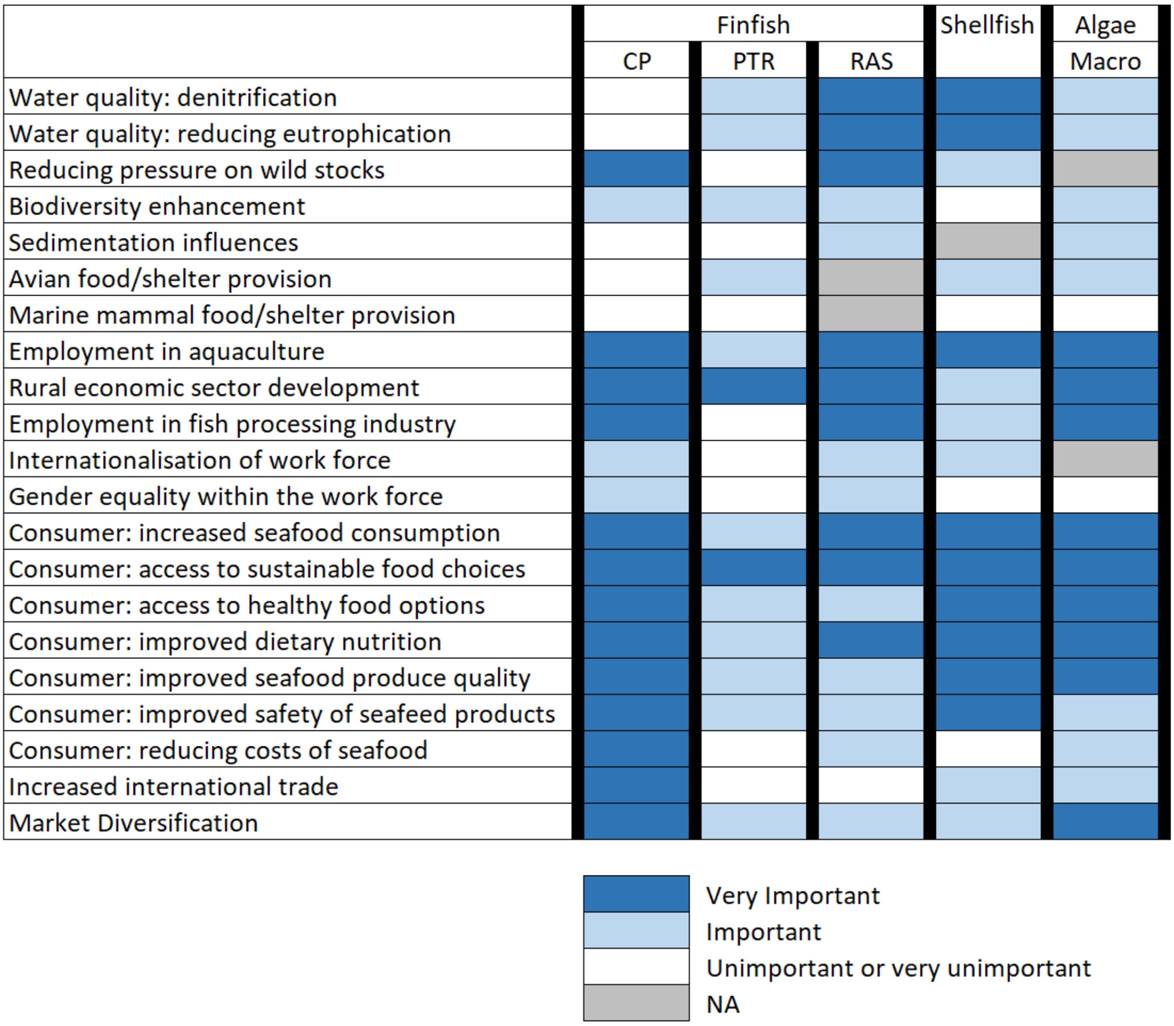

Figure 12: Key expert opinions on the important positive impacts of aquaculture by broad taxonomic and technology classifications. CP = cages and pens, PTR = ponds, tanks and raceways, RAS = recirculating aquaculture systems. Note: Opinions are not comparable among technologies and should not be compared.

[4] *In situ* (Latin) meaning "on site" or "in position”. It can mean "locally", "on site", "on the premises", or "in place" to describe where an event takes place and is used in many different contexts. In this context it means aquaculture carried out in the natural environment.

Post-siting issues are very specific to aquaculture type. Primary concerns around cage and net culture were the potential impacts of chemical and pesticide use for the environment, wild stocks, and water quality; animal welfare issues in situ (including the spread of disease within the culture stock); as well as risks posed by escapes (via genetic introgression) and as vectors for disease to wild stocks; and potential transfer of medical and pesticide residue to consumers, as well as zoonosis. Some of these impacts are considered to be well controlled at present but remain of importance due to external public scrutiny (e.g. disease and parasites in aquaculture) and present world issues (e.g., COVID-19 and resultant interest in zoonosis).

For pond, tank and raceway culture only two important impacts were highlighted: fish feed quality and its implications for fish health, and effects of predator control on protected species (culling of cormorants, beavers and otters). Recirculating aquaculture systems highlighted a wide range of important potential negative impacts, despite the many benefits that the use of the culture type is likely to bring. The level of importance attributed to many impacts likely reflects the relatively recent development of recirculating systems and the resultant uncertainty, rather than necessarily the scale of realised impacts. Prominent concerns include potential to impact wild stock via unintentional introductions of species and disease (despite limited discharges); use of feed potentially sourced from at-risk species or stocks; medicine, chemical and pesticide use; impacts on water quality from the limited discharges from recirculating systems; and animal welfare and disease in cultured stocks.

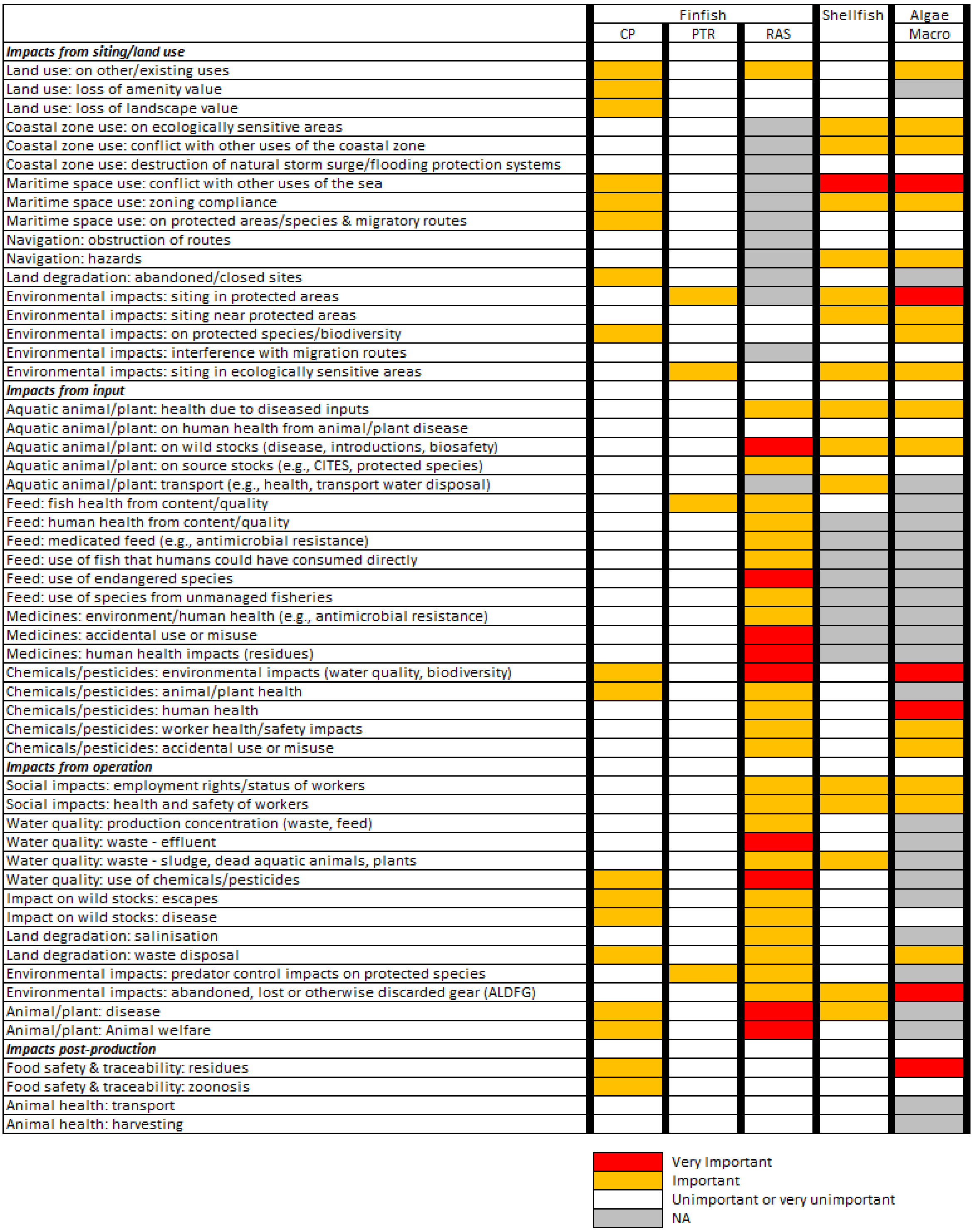

Figure 13: Key expert opinions on the important negative impacts of aquaculture by broad taxonomic and technology classifications. CP = cages and pens, PTR = ponds, tanks and raceways, RAS = recirculating aquaculture systems. Note: Opinions are not comparable among technologies and should not be compared.

Negative impacts of importance associated with shellfish culture included workers' rights, health and safety; unintended introductions of disease into wild stocks and the potential introduction of invasive non-native species (NNS); impacts on water quality via waste products; and potential impacts of ALDFG, particularly from suspended culture methods (e.g., longlines). Some similar concerns were also seen for macroalgal culture, including workers' rights, health and safety; the unintentional introduction of disease and invasive species, and impacts of ALDFG. Additionally, there were also concerns surrounding chemical and pesticide use in the culture of macroalgae and resultant residues in products.

3.2.2 Case study summaries

A series of 18 case studies were undertaken (21 planned, three merged, one not undertaken) across different geographic regions, taxa and aquaculture technology types (Annex 3). Case studies combined information acquired from reviews of the scientific literature (Task 1), additional scientific literature compiled by the case study authors (including white and grey literature), and information elicited through a series of semi-structured interviews with key experts based in national bodies responsible for the management and regulation of aquaculture. A total of 40 interviews (Annex 1) were conducted across case studies. Case studies examined agreement and disagreement between the scientific literature and key experts with regard to the primary positive and negative impacts of aquaculture. Agreement between the scientific literature and key experts is used to identify areas on consensus in impact importance, whereas disagreement indicates a potential need for future efforts in either research or research communication in order to reach consensus. Summaries of each case study are presented below.

3.2.2.1 Greece – sea cage – sea bream and sea bass

Greek sea cage aquaculture of sea bream and sea bass represents 58 % of total EU production of these species. Greece is the leading finfish producer in the EU following the UK's exit. Greek sea bass and sea bream production reached 120 500 tonnes in 2019.

The impacts from sea cage sea bass and sea bream aquaculture are largely in agreement with those identified in scientific literature and from key expert consultation. The main concerns in the scientific literature and of key experts are for *Posidonia oceanica* meadows less than 400 m from the sea cages because several adverse effects have been recorded. Both perspectives share concerns regarding the emission of waste products in both solid and dissolved forms, though these are highly localised (often up to 25 m from the cage). Key experts highlighted that more studies are needed to improve product quality and welfare. From the identified impacts in the scientific literature, those less understood and studied include escapes of farmed fish and competition for resources, genetic pollution, interaction of marine mammals, and underwater noise.

Both perspectives also recognise the importance of marine fish farming of sea bream and sea bass as a generator of economic wealth and employment, with key experts additionally identifying the specific role this plays in supporting rural development and employment opportunities in remote rural and island areas with limited alternative employment opportunities.

3.2.2.2 Croatia – sea cage – sea bream and sea bass

Sea cage aquaculture of sea bream and sea bass in Croatia produced around 12 800 tonnes in 2019, nearly double the volume produced only five years previously (3 870 tonnes, 2015). Approximately 65 % of all whitefish (which encompasses sea bass sea bream and shade-fish) production occurs in Zadar County.

The impacts from sea cage sea bass and sea bream aquaculture of greatest importance emerging from the scientific literature and from key expert consultation were broadly similar. Both perspectives share concerns regarding the emission of waste products in both solid and dissolved forms. Lack of coastline for vessel embarkment, live fish, and juvenile and/or harvested fish transportation from the farm to distribution channels restricts sectoral growth. Harmonisation of spatial plans for coastal area usage is needed between the counties and local governments. Competition for farming space might lead to price increases for farmed fish and products, slowing down production within the sector while bringing more environmental pressure that results in poorer quality of the product and the marine environment.

Both the scientific literature and key experts recognise the importance of whitefish aquaculture as a generator of economic wealth and employment, with key experts additionally identifying the specific role this plays in supporting rural coastal communities in Croatia. However, key experts expressed concern about the competitiveness of salaries and how this could undermine the growth of this sector in future.

3.2.2.3 Ireland – sea cage – Atlantic salmon

Irish sea cage aquaculture of Atlantic salmon represents 5.6 % of total EU (including the UK) production of these species. Ireland is the leading Atlantic salmon producer in the EU following the UK's exit. Irish Atlantic salmon production reached 11 300 tonnes in 2019 and accounts for 29.9 % by weight and 62.9 % (EUR 107 million) by value of all aquaculture production in Ireland.

The impacts from sea cage Atlantic salmon aquaculture of greatest importance emerging from the scientific literature and from key expert consultation were broadly similar. Both perspectives share concerns regarding the emission of waste products in both solid and dissolved forms. Similarly, both the scientific literature and key experts are concerned with the potential for aquaculture to harm the wild stocks of Atlantic salmon via increased resistance of salmon-associated pathogens to antimicrobials and other treatment agents and the threats posed by escaped individuals as vectors for pathogens, as well as potential weakening of stock fitness through genetic introgression. In addition, key experts highlighted the importance of transfer of sea lice between wild and cultured stocks and the fact that the treatment of sea lice in cultured stocks may increase sea lice tolerance to both artificial and natural treatments. Both perspectives also recognise the importance of Atlantic salmon aquaculture as a generator of economic wealth and employment, with key experts additionally identifying the specific role this plays in supporting traditional Irish-speaking rural cultures and communities, where choice of livelihood choices is often limited. The scientific literature also highlights the potential impacts of aquaculture construction and ongoing operation on protected, endangered and threatened species, specifically marine mammals, which reflects a growing academic concern surrounding the impacts of construction on the marine environment.

3.2.2.4 Poland – pond culture – carp

Polish aquaculture is connected mostly with inland production of carp – *Cyprinus carpio* (21 300 tonnes in 2019) and trout (16 200 tonnes, mainly rainbow trout *Oncorhynchus mykiss* in 2019). Other aquaculture species are produced in minority (3 700 tonnes in 2019). Carp is produced in earth ponds located mainly in the southern part of Poland. In general, impacts are recognised by local literature and key experts from the broader literature studies. Carp pond culture in Poland is reported as a small extensive fish farming sector with low environmental impact.

The most important environmental impact is that carp aquaculture is an inland water user. However, despite water retention, aquaculture uses water for production purposes and is in competition with more effective sectors like agriculture, animal husbandry or industry. The main environmental problem highlighted in the case study is sediment: sludge that require systematic removal (decomposing biogens) and management.

Both the literature review and the key expert consultation are in agreement on the positive environmental impact (ecosystem services) of the ponds on: the water-retention capacity of the ponds and the stabilisation of the water flow in the rivers that reduces the risks of floods during spring and autumn months, and protects against droughts during the summer months; and the rich biodiversity of the fauna, mainly birds, and flora in ponds in their immediate vicinity. The literature and the key experts are not in agreement regarding the impact of high nutrient loads, oxygen depletion and concentration of toxic substances (especially heavy metals) in streams receiving effluent waters from the carp ponds. Key experts confirmed an improved water quality of water flowing out of ponds in relation to the water flowing in but had concerns regarding the accumulation and management of sediments and sludge. However, the scientific literature highlights the negative impact of the water diversion to fish ponds on migration and reproduction of wild fish and highlights the shortcomings of the environmental research because of the lack of scientific support on: new and holistic research of carp aquaculture impact; complex research of environmental aspects; and valuation of ecosystem services provided by carp pond farming. The key experts recognise carp pond farming as a driver of economic development in some rural regions in Poland and are increasingly concerned by the competition for water usage between carp pond farming and more effective sectors like agriculture, animal husbandry or industry.

3.2.2.5 Germany – pond culture – carp

The production and consumption of common carp in Europe is limited to few countries (Poland, Czech Republic, Hungary and Germany). Production is either extensive or semi-intensive in natural- or man-made ponds and offers environmental benefits and negative impacts depending mainly on intensity of production. The literature review and the key expert interviews are in agreement on many socio-economic and environmental impacts of carp pond farming.

The literature review highlights the major positive effects of carp ponds on the microclimate and the river water flow by retaining excess water in spring and releasing the water in autumn when there is a temporary lack of precipitation. Both perspectives agree that carp ponds act as biodiversity hotspots and substitute habitats to reduced natural wetlands for many species, including endangered fish species, birds, protected predators and terrestrial mammals by providing a feeding and breeding ground. Both perspectives have concerns regarding the impacts of escapees from carp ponds and from uncontrolled stocking on the biodiversity of natural rivers. The literature review indicated concerns about uncontrolled carp imports and their role in spreading parasitic diseases and viruses. The literature highlights the low greenhouse gas emissions from carp ponds, the variability of the net nutrient emissions (nitrogen and phosphorus) and the risk of eutrophication, which depend on the intensity of production and the quality of pond management. Both perspectives have concerns about high emissions of nutrients and suspended solids occurring at carp pond harvest. The key expert consultation highlights the fact that even though carp farming is not the main contributor of income through employment, the whole value chain has indirect impacts on the local and regional economy, and cultural values: tourism, gastronomy, recreation, education and provision of ecosystem services.

3.2.2.6 Germany – raceways culture – trout

Germany was the largest market for rainbow trout within the EU in 2018. Flow-through farms use various rearing facilities, from traditional earthen ponds to concrete ponds to raceways, tanks, or basins of various shapes. Farms typically use sedimentation ponds or drum filters if they need to reduce the nutrient loads to fulfil water quality requirements. To protect the farmed fish from avian or mammal predators, more professional and big farms typically use nets and fences. The main production regions for salmonids in Germany were the two southern states Baden-Würthemberg and Bayern.

Key experts indicated that impacts from raceways trout aquaculture are largely characterised as limited negative and positive. The literature review indicated concerns about past nutrient emissions (nitrogen and phosphorus), antibiotics and hazardous substances from trout farms that had negative effects on ecosystems prior to strict regulation and monitoring enforcement during recent years. Intensive production creates nutrient loads, but these farms have mandatory cleaning obligations. The literature review highlights the positive impacts on wild fish stocks of the replacement of fish meal and fish oil in trout feed. Both perspectives share concerns about the health status and dietary value of farmed trout but acknowledge the reduced nutrient loading and contamination of rivers. The literature review is more concerned by the competition between native fish species and non-native rainbow trout originating from restocking rather than from trout farms. The literature review highlights negative economic impacts of predators such as cormorants, grey herons and otters on small trout farms but could not quantify the direct effect of trout farms on predator populations and natural biodiversity. Both perspectives recognise the low employment in the production sector but acknowledge the economic importance of the farmed trout value chain in small towns and villages (taxes, short and regional supply chains, domestic tourism). The key experts highlighted the concern regarding an aging workforce, strong competition for qualified and experienced employees, and this physically demanding farming activity.

3.2.2.7 Denmark – recirculating aquaculture systems – trout

Denmark is one of the largest producers of rainbow trout (*Oncorhynchis mykiss*) in the EU, with an annual (2018) production of about 47 000 tonnes. To lessen/remove the negative environmental impacts of traditional flow-through rainbow trout farming, and to comply with the EU Water Framework Directive water quality standards, recirculation technology has been introduced at large scale in Denmark during the last 20 years and almost half of the Danish rainbow trout production currently takes place in so-called in so-called model-trout-farms (MTFs). These semi-intensive RASs apply the most cost-efficient technologies from intensive RASs, and the introduction of MTFs has accommodated many of the negative environmental impacts associated with traditional flow-through farming. Damming (stream barriers) is no longer needed, water consumption has been reduced 20-fold, and water is treated and cleaned before it is discharged. Remaining negative environmental impacts concern a continuous, although significantly reduced, discharge of dissolved nitrogen and to a lesser extent dissolved phosphorus. However, promising technologies for mitigating this are currently being developed and tested/applied. Other important impacts, for which no mitigation measures currently exist (or are currently being developed), concern the high carbon footprint that MTFs can have depending on the energy source they apply and the feed they use (this applies not only to MTFs but to aquaculture productions of high trophic level species in general). As for evaluation of environmental effects (positive and negative), there was high conformity and compliance between literature and key expert perception. To some extent that also applied to social and economic effects, but it appeared as if key experts have a more holistic and somewhat nuanced approach than interest organisations, also taking rural development into account, for example, as well as overall food production issues. Interest organisations, representing opposite poles, were in good agreement on the positive impacts but seem to have more diversified opinions on potential negative impacts.

3.2.2.8 Portugal – recirculating aquaculture systems – sole

In Portuguese RASs the species produced are essentially sole (*Solea senegalensis*) and turbot (*Psetta maxima*). The majority of Senegalese sole produced in Portugal is by RAS aquaculture and stands at 121 tonnes. Almost all sole production is consumed in the domestic market, except for a small part that is exported mainly to Spain. Senegalese sole production has taken place essentially in southern European countries. Although the production volume is relatively small, it has increased exponentially in the last decade.

Most of the impacts identified in the scientific literature on aquaculture production in RASs were mentioned by key experts consulted in the interviews. In both perspectives, the low water consumption, the need for little space for infrastructure and work equipment, the existence of biofilters (colonies of microorganisms), and the great ability to control diseases that enter through pathogens were identified as advantages of RASs, but high energy consumption (electricity) was highlighted as a disadvantage (albeit with options for alternative sources). The scientific literature considers RASs to be intensive production systems and that they must comply with a maximum load of organisms produced, to safeguard animal health and welfare. In the case of key experts, it is often mentioned that an RAS is a very controlled system, where effluents are very concentrated, but that occur in small amounts. Key experts also point out that RASs can generate skilled jobs, regardless of gender, and that production through this system has a positive socio-economic impact by producing high-quality species at a more affordable market price.

3.2.2.9 Portugal – integrated multitrophic aquaculture – Various

IMTA is a new and emerging technological approach to aquaculture and has, thus far, had limited uptake commercially in Portugal. There are currently no commercial enterprises conducting IMTA aquaculture in Portugal because there is perceived to be no prospect of an economic return at present, which is a significant obstacle to the growth of IMTA. Further, there is a lack of clarity regarding commercialisation of the supplied products under this system.

There are several impacts that have been identified for IMTA and that are common in the scientific literature and in interviews with key experts. In both cases, IMTA is seen as a sustainable practice that consists of the use of several species from different trophic levels simultaneously, allowing for a chain interaction: nutrients produced at each trophic level are used at other levels, completing a cycle of nutrients. However, IMTA exhibits many of the other negative impacts associated with the culture of finfish, shellfish, algal and any other species – the impacts of IMTA are therefore largely dependent on the combination and trade-offs amongst the species selected for culture.

According to the scientific literature, the other main advantage of IMTA is the possibility of diversifying the yields produced. In consultation with key experts, additional positive impacts were identified such as the social acceptability of the activity, the possibility of generating employment for a wider range of technicians related to the various species produced, and the possibility of generating a broader economic impact by being able to monetise the production of various species of different trophic levels.

3.2.2.10 France – tray culture affinage in ponds – oysters

The most commonly used aquaculture method for oyster cultivation in France, accounting for 60 % of the total production, is the use of intertidal trestles. These consist of metal frames or tables on which young oysters are placed in grow-out bags on the intertidal zone of the shore.

The impacts of the tray culture of oysters that emerged from the literature review include sedimentation modification and effects on benthic community, nutrient cycling and seston depletion, physical disturbance and shading, habitat creation by farm structures, effects on fish and seabirds, non-indigenous species and pest organisms. Unforeseen circumstances meant that the findings from literature could not be verified in a case study via a key expert consultation.

There is no specific regulation related to oyster aquaculture on racks. Both European and French regulations are general and related to aquaculture including oysters. Specific provisions are made under French regulations with regard to shellfish culture and the organisation of the shellfish industry including oysters.

The most profound mitigation pathways are management of pests and diseases, adequate farm and site management, and monitoring to prevent disease spread and to ensure food safety of shellfish products, including oysters, to the consumer.

3.2.2.11 France – additional pond affinage – oysters

The practice of oyster affinage or refining, ripening, fattening and greening at the end of the production cycle consists of immersing adult oysters for a few weeks in shallow ponds rich in phytoplankton of the diatom *Haslea ostrearia*. This greening is economically exploited in France to give added value to oysters before packing them for marketing.

The impacts of additional pond affinage of oysters of greatest importance emerging from the literature review are nutrient cycling, seston depletion and effects on zooplankton and fish. Unforeseen conditions meant that the impacts found in literature could not be verified via a key expert consultation.

With nitrogen abundant in the estuarine feeding waters of oyster ponds, low turbidity and sufficient light penetration in the shallow pond water column, the development of phytoplankton blooms necessary for the greening of oysters is stimulated. Further, oyster ponds show fluctuations in phytoplankton population and richness, and depletion of the seston as a result of oyster filtration and phytoplankton sedimentation. Because of the significant variations in temperature and salinity in refining ponds, a limited number of species can survive in oyster ponds, with copepods dominating the zooplankton. A few species of pelagic fish prefer oyster ponds to offshore waters for their protection as a nursery place.

3.2.2.12 Netherlands – bottom culture – mussels

Mussels (blue mussel) and oysters (European flat oyster and Pacific oyster) are bottom culture in the Oosterschelde and Wadden Sea. Mussel seed is derived from natural seed mussel trawling and roughly half is sourced using mussel seed Collection Devices (MSCDs). The impacts of greatest importance according to key experts are in line with the general literature study. However, some specific impacts arise in the Netherlands as a result of legal and cumulative effect identification.

Mussel farming is referred to as ‘agriculture at sea’ by the literature and key expert groups, indicating their perspective on mussel farming. For nature organisations, this label is a negative one, as they position agriculture as opposite to nature, as something not belonging in a nature area. For the mussel farmers it is a positive label, as it shows that they are not harming nature but working together with nature and creating nature (i.e., mussel beds, food for eider ducks) at their cultivation parcels. The view on positive and negative impacts perceived by key experts, may therefore be interpreted differently.

Specific impacts from nitrogen deposits resulting from shipping activities, are mitigated through the licensing procedures. These procedures focus on calculated nitrogen contributions per nitrogen-sensitive Natura 2000 area, based on calculation points that overlap with habitat types and/or that are designated under the Nature Conservation Act.

Specific negative impacts on the socio-economic side relate to the health and safety of workers using MSCDs; the financial position of part of the sector; and conflict with other uses of the coastal zone.

The main issues that key experts and local scientific literature disagree on are: nitrogen deposition in sensitive Natura 2000 areas, tourism attractions, local branding of rural areas, and the potential role of microplastic pollution.

3.2.2.13 Spain – suspended culture – mussels

Spain is the largest producer of mussels in Europe, with 236 900 tonnes produced in 2020 with a total first sale value of EUR 106.7 million. Galicia, located in the northwest of Spain, is by far the largest production area in the country, producing 98 % of all Spanish mussels. In the Spanish Mediterranean area, the autonomous communities producing mussels are Catalonia, the Valencian Community, Andalusia and Balearic Islands, which combine to produce the remaining 2 %.

Mussel aquaculture in Spain is dependent on mussel seeds collected from wild populations or imported from other areas. Grown on floating or static rafts (mainly in estuaries) and on longlines (more often used offshore), mussel farms are family-owned businesses.

In general, the scientific literature and key experts do agree that particle immobilization, elimination of seston (phytoplankton, suspended particles), capture and harvest of organic matter, improvement of water quality, biodiversity and change in taxonomic composition are positive impacts related to mussel aquaculture in the Spanish Mediterranean area, while the deposition of organic matter and sediment habitat conditions could be considered as negative impacts.

Key experts highlighted that wild seed collection could be problematic in some regions, but it is usually a well-managed, controlled and monitored process that minimises possible negative environmental impacts.

3.2.2.14 Ireland – suspended culture – mussels

Irish longline culture of blue mussels represents 3.3 % of total EU (including the UK) production of these species. Production of blue mussels in Ireland peaked at 39 300 tonnes in 2003 and has declined substantially since 2007. Irish blue mussel production reached 15 200 tonnes in 2019 and accounts for 40.0 % by weight and 8.71 % (EUR 14.8 million) by value of all aquaculture production in Ireland.

The impacts from rope-grown blue mussel aquaculture of greatest importance emerging from the scientific literature and from key expert consultation showed some evidence of overlap. Both perspectives share concerns regarding the emission of solid waste products and the depletion of seston in the water column through consumption by mussels. The scientific literature identified the possible positive role of mussel aquaculture in the denitrification of the surrounding environment and potential contribution to water quality remediation. Further, mussel aquaculture may influence local community structure and composition and the collection of mussel spat from wild mussel beds to stock farms may reduce the wild stock’s reproductive success. Key experts noted that the translocation of mussels or their spat could facilitate translocation of non-native species, pathogens, and parasites to new wild populations. Key experts also identified a potential risk to humans in terms of food safety, particularly from food-borne illness, though this relates to the consumption of bivalves generally rather than farmed mussels specifically.

Both the scientific literature and key experts recognise the importance of blue mussel aquaculture as a generator of economic wealth and employment, with key experts additionally identifying the specific role this plays in supporting traditional Irish-speaking rural cultures and communities where choice of livelihood is often limited.

3.2.2.15 Portugal – various – clam and oysters

Shellfish production is the primary component of Portuguese aquaculture production, representing 57 % of the total produced and 63 % in terms of value. Clams and oysters represent around 92 % of the molluscs produced. Around 3 832 tonnes of European clam were produced in 2017 and the species is widely exported to European markets, particularly Spain and France, but new niches in the domestic market are being opened. Around 1 154 tonnes of oysters were produced in 2018. The production of clams is essentially carried out on plots of land (*viveiros*) located in lagoons and estuaries. Seed clams are collected from wild seed banks and upon authorisation given by the entities that regulate the activity. Inland production is mostly extensive. Offshore production is still not consistent either for clams or oysters. Almost all oyster production comes certified from the hatchery. In Portugal only, oyster fattening is done. Oyster and clam production occurs in approximately the same places. There is no great tradition of consuming oysters in Portugal, but this emerging market appears to cater primarily to the tourist market.

Both the scientific literature and key experts agree on the potential impacts. The pressure made by the *viveirista* (i.e., the bivalve producer) to the clam seed banks could be considered negatively (i.e., pressure on the natural banks when removing the seed), but also from positively (i.e., it repopulates areas lacking clams). One negative impact relates to entry of diseases that affect bivalves and can decimate populations. Non-indigenous bivalve species can inflict negative impacts on ecosystems because they generate imbalances by competing with native species. The scientific literature points out as a positive impact the possibility of using bivalves as biomarkers. Key experts state that the eutrophication that can occur in the sediment is a negative impact on shellfish production. The bivalve production process is one of monoculture, where the habitat and existing species are eradicated. Positive impacts on shellfish production are the growing ecological literacy of producers, allowing them to be more aware of sustainable production. Also, the scientific literature and key experts recognise the importance of clam and oyster aquaculture as a generator of economic wealth and employment.

3.2.2.16 France – macroalgae

The growing interest in seaweed aquaculture represents new opportunities for the multiuse of the maritime space and the sustainable production of seaweed while providing a series of ecosystem services such as bioremediation and carbon uptake.

France has a long tradition of seaweed gathering. The main source of macroalgae biomass in France is from harvesting of wild seaweeds. However, aquaculture is also occurring at a fully commercial scale with sea-based (coastal) or land-based production facilities. In 2019, France produced 51 476 tonnes of seaweed, equivalent to 18 % of the total European production, of this 0.3 % was from aquaculture sources. Main species farmed in open waters include *Undaria pinnatifida* (wakame), *Alaria esculenta* (winged kelp) and *Saccharina latissima* (kombu or sugar kelp), while *Ulva* and *Chaetomorpha* (sea lettuce) are commonly cultivated in land-based facilities.

In Europe, seaweed farming is still in its infancy and carried out at a much smaller scale compared with that seen in other countries (for example, China). For this reason, there is limited evidence in published literature of impacts of seaweed aquaculture in Europe. Literature reviews in task 1 have shown that seaweed farming has multiple effects: taking up inorganic nutrients from surrounding waters (nutrient bioremediation) alleviating marine eutrophication, potentially mitigating algal blooms, and improving local environmental status. Macroalgae can also bioremediate heavy metals and some pesticides (phyco-remediation) and can remove aqueous CO_2 while oxygenating the water column. By taking up CO_2 from seawater, seaweeds can buffer localised water acidification, acting as a refuge for calcifying animals. Seaweed farming can have positive effects on the benthic infauna under/near the farm, increasing its abundance and richness. Macroalgae farms provide substratum and habitats for a wide variety of associated organisms, both mobile and sessile.

Seaweed farming can attenuate wave action and alter local hydrodynamic, slowing water velocity, consequently impacting sedimentation rates and sediment dynamics. This may not always be seen as a negative impact, particularly for areas requiring coastal protection. Culture of seaweed can also affect the light climate in the area under the farm by shadowing benthic communities, particularly benthic vegetation. Another effect of seaweed farming is the enrichment of organic matter in the surrounding benthic environment due to loss of seaweed biomass; localised accumulation of seaweed debris may also stimulate production of volatile gases such as methane. While macroalgae farms can provide shelter and food for a variety of organisms, they can also provide a stepping-stone for the potential introduction of non-native species, which could affect abundance of keystone species, and introduce genetic pollution as well new pathogens and diseases.

Interviewed key experts agreed that seaweed aquaculture can provide positive and negative impacts under the environmental, social and economic spheres. However, the entity and types of impact are related to factors such as the scale of the farming activities, the location, the species cultivated, etc. Main impacts currently perceived by the key experts are related to conflicts with other activities in the coastal area and potential environmental effects such as introduction of non-native species, accumulation of seaweed biomass after storm events, etc. Other impacts that may become important with the development of the industry include emergence of diseases, potential uses of chemicals (pesticides and fertilisers), biosecurity (for example, invasive species and interbreeding between farmed and wild populations).

Social acceptance of farming activities is highly important and presents a major obstacle to the growth of this sector. Stakeholders in France are trying to support acceptance of the industry by actively communicating and engaging with local communities, NGOs and industry, with the support of the French scientific community to provide evidence of potential impacts.

3.2.2.17 Spain – macroalgae

The Spanish macroalgae sector is mainly characterised by exploitation of wild algae collected manually on foot or by diving in the Cantabrian and Galician coastal areas (northern Spain). However, macroalgae aquaculture, carried out on land and in marshes/estuaries in Galicia and Andalusia, is relatively small. Current declarations of production are small, with only 7.28 tonnes declared in 2020 (valued at EUR 14 281). This production is substantially higher that in 2016, when it stood at only 0.04 tonnes.

In general, the scientific literature and consulted key experts agree that CO_2 removal, slowing water currents and depletion of nutrients are positive impacts related to macroalgae aquaculture, while the impact to the benthic habitat could be considered as negative. Marine spatial planning is considered increasingly important in selecting sites with sufficient water depth and flushing to avoid long-term effects, and to avoid conflicts with other uses.

Although the techniques and knowledge necessary for large-scale marine aquaculture of the order Laminariales (kelp) is available in Spain, macroalgae aquaculture is a developing activity and, if substantial growth occurs, could become economically and socially important. However, at present, its economic and social value is minimal.

3.2.2.18 Germany – microalgae

Germany has the largest number of microalgae production companies in Europe and is number four in European *Spirulina* producers (Araújo et al., 2021), although microalgae production in Germany is still a relatively small industry sector. Key experts largely describe and assess the current situation in microalgae production and the literature review mainly focuses on available research data and published studies and policies, with less direct information from commercial producers.

Because of its small scale, applications in this field have low cumulative impacts on the environment and economy. Key experts and the literature mention the importance of controlled production environments. Thus, process monitoring and management and the concept of the production system itself need to be addressed with high priority and will play an important role in safe production applications at large scale in future applications. As for positive effects, the literature and key experts have the same focus. The possibility for the potential production of microalgae biomass on marginal land is seen as one of the major aspects, as agricultural land is limited and the need for food production is increasing.

Another important environmental impact with positive effects is the bio-economic integration of microalgae production processes. The bio-fixation of CO_2 and the potential use of wastewater streams and coupling processes of material streams are mentioned as important (potentially positive) aspects. In particular, the photosynthetic conversion of sunlight into chemical energy with 5 to 10 times higher efficiency in comparison to land plants make microalgae a suitable and promising player in CO_2-sequestration strategies. The potential use of wastewater as a nutrient source for microalgae cultivation and as a remediation step are mentioned both in the literature review and by key experts. Nevertheless, key experts explain, this is as yet a potential benefit and is currently not applied in commercial applications. Negative impacts mentioned by the literature are mainly in relation to uncontrolled cultivation conditions. According to the key experts, ubiquitous microalgae are used for commercial-scale applications in Germany; thus, the potential risk of release of culture cells into nearby ecosystems is estimated to be very small. The use of genetically modified microorganisms is forbidden in Germany.

3.2.2.19 Greece – microalgae

Greek culture of microalgae reached 142 tonnes dry weight in 2019, with associated revenues of EUR 1.39 million. The culture of microalgae is in its infancy and further growth is challenging as total (imports and Greek production combined) supply currently matches consumption in the Greek market. In order to expand, Greek producers must improve their share of the domestic market and/or open new market channels in Europe, which are currently supplied by the USA, taking advantage of the superior quality of Greek *Spirulina* – largely a result of the drying methods used for imports.

There is a noticeable lack of robustness of available underlying data for Greek microalgae aquaculture that prevents a comprehensive analysis of the current situation. Official statistics on microalgae production volumes are almost non-existent at the European scale and often FAO, Eurostat and National data do not match, and STECF Economic Reports of the EU Aquaculture sector do not include yet microalgae in their analyses.

The scientific literature and key experts were in agreement regarding the most significant impacts of microalgae aquaculture, although the scientific literature impacts are theoretical and there is no measurable evidence in the field in Greece because the existing facilities are small scale. Both perspectives share concerns regarding the water requirements, especially in water-constrained regions (which is not the case in Greece), as well as the need to closely monitor the quantities of heavy metals in the cultivation medium to avoid potential effects on consumers' health. The scientific literature expresses concerns about terrestrial impacts, ecosystem impacts and the supply of and demand for energy and nutrients. Although acknowledged by the key experts as theoretical impacts, there is as yet no measurable evidence of negative environmental impacts from microalgae cultivation in Greece. Some units operate in Natura areas, showing that microalgae cultivation is compatible and can co-exist even in environmentally sensitive areas.

Key experts highlighted the importance of microalgae aquaculture for income generation and employment in rural areas that benefit from the presence of geothermic fields that can aid microalgae production. The scientific literature also highlights the potential positive atmospheric impacts of biofixation of CO_2 as well as the negative possible biogenic emissions affecting ozone and formation of secondary organic aerosols that can contribute to the greenhouse gas emissions.

4 EVALUATION OF IMPACTS

4.1 Comparison of scientific literature and key expert opinions

There is evidence of clear consensus between the scientific literature and key experts on a number of prominent impacts from aquaculture, conveying certainty in their importance.

In terms of positive impacts, both the scientific literature and key experts clearly acknowledge the importance of aquaculture in providing greater access to seafood for EU citizens (Figure 6, Figure 12), alongside the associated benefits to food security, food quality, and health and nutrition. This improved access has also contributed to a reduction, or at least stabilisation, of pressure on wild stocks where aquaculture is able to meet an increasing proportion of demand from consumers (Figure 6). However, as production from capture fisheries declines, the production from aquaculture has not risen to make up the shortfall, leaving the EU increasingly dependent on imports. This suggests that the access to seafood provided by aquaculture is, at least partly, attributable to increases in aquaculture outside the EU rather than within the EU.

Employment (Table 3, Figure 12), particularly of low-skilled nationals (Figure 10, Figure 11) often in rural areas, is a key positive impact of the aquaculture sector. However, the lack of contemporary expansion in the EU's aquaculture sector is reflected in stable, rather than growing, numbers of enterprises and in declining employment in the sector. Declining employment in a sector that has largely stagnated in terms of growth may threaten the future of rural communities for which aquaculture provides a major source of employment and income.

Consensus is also seen with some of the negative impacts of aquaculture. There is broad concern from both scientific literature and key experts (Figure 2, Figure 3, Figure 13) about the potential effects of *in situ* aquaculture (e.g., finfish in cages and pens, shellfish suspended culture, and macroalgae suspended culture) and its potential to result in the introduction of non-native species or to result in genetic introgression and weakening of wild stock fitness through either escapes and subsequent breeding (finfish) or the release of gametes/spat into the local environment (shellfish and macroalgae).

Similarly, both the scientific literature and key experts remain concerned about the use of pesticides, chemicals and medicines to control parasites and infection across finfish aquaculture (Figure 2, Figure 13). This mainly relates to the potential impacts of their use on the development of anti-pesticide and anti-microbial resistance in disease-causing parasites and microbes. While regulations for the use of these substances are in place, there is still uncertainty about the long-term effects and implications of even controlled exposure. Additionally, where the scientific literature had a prominent focus on the potential impacts of parasites, diseases and disease-causing bacteria, particularly with regard to subsequent infection of wild stocks by farm stock, these impacts were felt to be largely well controlled by key experts. Existing controls of parasites and disease appear effective and, at least in the first instance, are likely contracted by culture stock via wild stocks rather than vice versa. In scientific literature disease pressures are found to be abundant, persistent and require management. Key experts also expressed concern about the use of pesticides, chemicals and/or medications in shellfish and macroalgal culture, though this was not as prominent in the scientific literature and use in these culture types is far more limited than for finfish.

Both the scientific literature and key experts expressed the importance of effluent discharge, either as dissolved matter or solid organic matter, and its potential for localised impacts to biochemical cycles, nutrient loads and community structure (Figure 2, Figure 13). Both perspectives acknowledge the small area of impact of effluent release at current culture densities but express concern on the occurrence of substantial increases in current aquaculture activities, particularly if aquaculture sites are closely clustered or densities are increased.

In addition, key experts expressed concerns more broadly (i.e., beyond parasites and disease) around animal welfare in aquaculture settings. Animal welfare is an increasingly prominent topic in both the public eye and within the aquaculture sector. Animal welfare did not appear prominently in the scientific literature, likely reflecting continued debates around wider issues such as the ability or not of fish to feel pain rather than a lack of scientific interest within the aquaculture sphere. Welfare in aquaculture will undoubtedly grow as an impact of relevance to scientists, practitioners and regulatory bodies and is a clear priority moving forward. The addition of welfare working groups in, for example, the Aquaculture Advisory Council is a clear indication that this potential impact is being taken seriously by the sector.

Key experts also expressed concern about the potential impacts of ALDFG used in aquaculture, especially in the culture of shellfish and macroalgae (suspended cultures). This concern forms part of the more general topic of anthropogenic litter, which is of wide and increasing scientific, sectoral and public interest. The contribution of fisheries to this issue has received substantial attention but the contribution of aquaculture has received more limited attention.

Lastly, key experts pick out a number of infrastructure impacts that relate to the siting of aquaculture facilitates. Siting regulations are often specified in the licensing requirements as specific to aquaculture facilities and have cross-sectoral and planning implications. Siting impacts are not well addressed by the scientific literature, likely reflecting a lack of wider scientific interest rather than a lack of importance.

4.2 Aquaculture type: finfish sea cage

Below is summarised the major impacts of finfish sea cage and net pen aquaculture according to the scientific literature and the key expert consultations undertaken in this project (Table 4). Information is draw from the relevant literature review (see section 3.1.4.1) and case studies (see sections 3.2.2.1, 3.2.2.2, and 3.2.2.3).

Table 4: Summary of impacts from sea cage finfish culture

Impact	Scientific literature	Key expert
Positive impacts		
Income	✓	✓
Employment	✓	✓
Negative impacts		
Solid organic waste	✓	✓
Dissolved metabolic waste	✓	✓
Medicines and chemicals	✓	✓
Genetic introgression (escapes)	✓	✓
Marine area use conflict		✓

4.2.1 Socio-economic impact

According to EU Multi-annual Plan (EU-MAP) as component of the Data Collection Framework concering the marine finfish data, three European countries reported marine production: United Kingdom (156 633 tonnes, 93 % of European production), Ireland (12 236 tonnes, 7 %) and Spain (64 tonnes, less than 1 %). Ireland was the main EU producer. Salmon aquaculture in Ireland contributes approximately EUR 8.69 million in wages and salaries to the approximately 225 workers in the sector, of whom 191 are full time (STECF 20-12).

The combined global production of European sea bass and gilthead sea bream almost doubled during the 2008–2018 period from 245 300 tonnes valued at USD 1 480 million in 2008 to 464 000 tonnes valued at USD 2 247 million in 2018. Twenty-six countries were producing one or both species in 2018. Leading production countries are Turkey and Greece. Most of the firms combine the production of the two species, and volumes of each may change yearly according to the demand, prices and fingerling availability. When the price of sea bream decreases, producers usually increase the production of sea bass for a stable financial result at company level and vice versa.

In Greece, 66 companies operate 302 cage farms and employ 4 160 people directly (2019 data). The industry also offers employment directly and indirectly to about 12 000 people in ancillary sectors (equipment, packaging, fish feeds, transportation, services, etc.) – for workers, scientific, technical and managerial personnel. Most importantly, these **jobs are created in remote coastal areas**, contributing significantly to the economic and social development of local communities.

The EU Member States Croatia and Cyprus have also increased sea bass and sea bream production volume considerably since 2008, whereas the main EU production Member States Greece, Spain and Italy increased production volume at a lower rate in the same period – by 19 %, 10 % and 6 %, respectively. Non-EU producing countries Turkey, Tunisia and Egypt had further increased the production volumes for both species. Therefore the volume share of the EU producer countries has decreased from 60 % in

2008 to 38 % in 2018. Accordingly, the value share of the EU producer countries has decreased from 65 % in 2008 to 50 % in 2018 (FAO, 2021).

4.2.2 Environmental impacts

Cages suspended in water bodies are open systems. Inputs provided to the fish may diffuse into the surrounding water body and affect the wider environment. The same is true for waste products and metabolites. The principal input is feed, normally high-grade protein-rich formulations. Waste comprises uneaten food and faecal material, forming solid particulates rich in organic carbon, and soluble products of nitrogen and phosphorus excreted through kidneys and gills.

The **solid organic waste** tends to sink through the cage and settle on the bottom under the cage. Decomposition of the particulates can cause significant abiotic and biotic impacts in the benthic sediment. As decomposition proceeds, the abiotic environment shifts from aerobic to progressively anaerobic conditions with decomposition shifting to sulphur bacteria and sulphide, which is highly toxic, as a waste product. Low oxygen and increasing sulphide have negative impacts on the biotic community, resulting in lower biodiversity and a shift in the species composition. These benthic impacts are commonly addressed by aquaculture regulators. In conducting a review of benthic impacts from cage aquaculture globally, Hargrave et al. (2008) concluded that sulphide levels at 1500 µM tended to coincide with a sediment redox potential of 0 mV where oxygen use in respiration just equals oxygen supply; any increase in sulphide with more progressive anaerobic decomposition is correlated with a reduction in diversity and a shift to the more pollution-tolerant species as represented by appropriate biotic indicators. These limits have been widely adopted as a guide by regulators.

The accumulation of particulates is, however, a function of settlement and current regimes. To define the likely spread of these impacts a number of models have been developed, such as AUTODEPOMOD, which take the hydrological variables to predict the most likely zone of effect of the farm as part of the effort to mitigate these benthic impacts.

The **soluble metabolic waste** contains inorganic nitrogen and phosphorous, both potentially limiting factors in phytoplankton productivity. Inputs of nitrates and phosphates as they diffuse out into the receiving water can potentially increase the trophic status of the water body with the possibility in some circumstances of causing eutrophic conditions and changes in the planktonic community. Under EU legislation many coastal waters, including those with farms, are monitored and given a water quality classification. Regular water quality monitoring is required with a view establishing if water quality classification is declining under the negative impacts of outputs of aquaculture and those from other users. Any changes caused by aquaculture would be noted but it is not a common occurrence.

A number of factors modify the risks of these impacts from feeding. Firstly, feeding rates change over the production cycle, more enclosed sites tend to hinder dispersion and make negative effects more likely and seasonal changes in such things as temperature increase the rate of decomposition so that the rate of benthic respiration is highest at the end of summer.

Other inputs may also disperse into the surrounding receiving water, including **medicines and other chemicals**. These are biologically potent and may affect wild populations although the intent is that they are present in such small concentrations as to be diluted below the active level beyond the edge of the farm. This is particularly important in the case of antibiotics since widespread use and distribution can increase the risk of resistance developing, which is a particular problem if extended to antibiotics used for human treatments and consequently as a threat to human health. In the case of salmon treatment of sea lice, this is a particular problem since it uses a number of therapeutic chemicals, several related to insecticides, which are likely to kill a range of other crustacea. It is not clear how far active doses extend beyond farms. It has been claimed in Europe that the increase in sea lice associated with salmon farms, together with the treatment, have been largely responsible for the large reduction in abundance of wild Atlantic salmon although, again, without definitive proof.

Non therapeutic chemicals can also be a risk, particularly in floating cage structures, which may require the use of anti-foulants, commonly copper based, to keep nets and structures clear of encrusting organisms. The treatment may dissolve in the water but also may flake off and sink to the bottom where, in the case of a heavy metal such as copper, it can bioaccumulate through the food web, even into seafoods used for human consumption.

A common problem with cages is that they can be damaged by storms and wave action. This can lead to **escape incidents** and the possibility of the 'domestic' strain, being of a different genetic background to the local wild type, interbreeding and causing **introgression of the genetic makeup of the local populations**. This may be less likely where the wild stock has a complex migratory life cycle as in the case of Atlantic salmon but rather more likely in marine spawning species such as sea bass and sea bream. If the fish in culture is an exotic for the area, there is the possibility of escapes forming an invasive population.

Artificial aquaculture feed is used most often in cage farming centred on essentially carnivorous fish. The feed has a high protein content and is usually derived from fish meal. Salmon, sea bass and sea bream, along with other species currently in cage culture, form the basis of substantial production sectors that require an equally substantial amount of feed. The fishmeal is derived from so-called forage fisheries based on **small pelagic species that have** reached the limits of exploitation, and in some cases are threatened with overexploitation as a result of demand from aquaculture, amongst other livestock sectors. These species, are considered suitable as a food protein source as well. Consequently, the demand on these fisheries is a potential negative impact on their potential for sustainable management. This is being mitigated through time by substitution with alternative protein sources, including from algae, leguminous plants principally soya or by raising strains not quite so dependent on fish meal but, even so, fish higher up the food chain still require more fishmeal than those lower down the chain, such as carp.

Cages, like any floating or moored objects, may cause **obstructions or impact the rights of access and navigation** of other users of the water body. Further, they may result in visual impacts such as loss of **amenity value and disturbing the landscape**. These are normally dealt with at the planning and licensing phase as the authorities try to balance the rights of users and the possibility of negative impacts.

4.3 Aquaculture type: ponds, tanks and raceways

Below is summarised the major impacts of finfish ponds, tanks and raceways aquaculture according to the scientific literature and the key expert consultations undertaken in this project (Table 5). Information is drawn from the relevant literature review (see section 3.1.4.2) and case studies (see sections 3.2.2.4, 3.2.2.5, and 3.2.2.6). Under pond culture, two different species are discussed (carp and trout) which display both shared and species-specific effects.

Table 5: Summary of impacts from pond, tank and raceway finfish culture

Impact	Scientific literature	Key expert
Positive impacts		
Income	✓	✓
Employment	✓	✓
Food security	✓	
Healthy food options		✓
Ecosystem services	✓	
Regional development	✓	
Phosphorus sink		✓
Biodiversity	✓	✓
Negative impacts		
Labour conditions		✓
Solid organic waste	✓	✓
Dissolved metabolic waste	✓	✓
Genetic introgression (escapes)	✓	✓
Health of wild predator species	✓	

4.3.1 Socio-economic impact

Common carp (*Cyprinus carpio*) is by far the most important cyprinid species in the EU by volume and value, although various other cyprinid species are produced. According to FAO data, EU member states (including the UK) produced 75 348 tonnes of common carp in 2018. A slight increase in production occurred between 2008 and 2018, equivalent to about 5 %. In total, Poland, Czechia, Hungary, Bulgaria, Germany, Romania and France are responsible for more than 90 % of EU carp production. Poland and Czechia alone have a share of more than 50 % of total EU production. The value of common carp sales was EUR 175 million in 2018. With the exception of Czechia, EU production of common carp is produced for domestic markets.

All respondents emphasised the positive image of the industry as a provider of **healthy food** and **numerous ecosystem services**. Carp aquaculture is a **driver for development** in some rural regions in Poland like Barycz Valley (Milicz area), Carp Valley (Zator area), Bełżec etc., where carp aquaculture stimulates the whole economy in the region. Traditional extensive polycultural techniques are still used by many present-day carp farmers in Europe. Hence, carp farms are seen as low-input aquaculture, providing both cultural and ecosystem services. In some countries like Germany a societal debate has started, which argues to acknowledge carp cultures for their provided ecosystem services. Carp farmers already receive public payments from contractual nature conservation under specific restrictions.

Global production of rainbow trout (*Oncorhynchus mykiss*) increased during the 2008–2018 period from 518 000 tonnes valued at EUR 1 952 million in 2008 to 848 000 tonnes valued at EUR 2 608 million in 2018. Different production systems are used in trout aquaculture. In Europe, most rainbow trout are produced in freshwater. A few countries also produce rainbow trout in marine waters in cages and RASs. The leading producer is Norway, with Denmark and Finland having smaller production in the Baltic Sea.

The level of EU production of rainbow trout decreased in the period 2008–2018, from 204 000 tonnes to 187 000 tonnes; however, the value of production increased from EUR 590 million to **EUR 739 million in 2018**. The leading EU producers are Denmark, Italy and France. The three countries covered 67 % of the total volume and 61 % of the total value. Enterprises engaged in trout production in the EU in 2018 numbered 2 218, which was a slight reduction from 2 241 in 2017. The enterprises **employed 6 243 people**, corresponding to 4 332 FTE.

Freshwater trout farming is carried out by professional and by start-ups or those entrepreneurs who do have another job next to the small trout farm (here: part-time farms). The majority of production comes from large professional farms, but most farms are small part-time operations. In recent years, part-time farms have been excluded from official statistics, which makes it hard to track their exact numbers. Locally, the sector is of economic importance, especially in combination with the (local) value chain of direct sales and gastronomy. Because of the negative development of production and concerns over increasing effects of climate change, which affect the potential of farming trout in these areas, the sector has **problems attracting qualified employees**. Therefore, the farms are in high competition for good employees and try to offer the best possible working conditions. Nevertheless, the work is still **physically very demanding** and includes weekend work. The freshwater trout sector has a significant component of part-time workers (0.71 ratio between FTE and employment). Consumers see trout as a healthy and convenient product in Europe. They favour the product quality, comparatively low number of bones, favourable portion size, and comparatively high nutritional value.

4.3.2 Environmental impacts

Culture in ponds means that inputs for culture, food, medicines, therapeutics and food or feeding supplements such as fertilisers are initially added in an enclosed space. The extent to which those inputs affect the wider environment and the receiving water depends upon the extent of discharge from pond to receiving water. Trout are predators, originally adapted to living in clean, fast-flowing upland rivers, whilst carp are more omnivorous and are found typically in slow-moving, deeper lowland reaches as well as lakes. The two therefore have rather different requirements, which is reflected in the profile of the impacts they can generate. Trout in culture generally means the rainbow trout Oncorhynchus mykiss, a native of North America and an exotic to Europe, although other species are reared, such as char species (*Salvelinus spp*) or brown trout (*Salmo trutta*). Carp is generally the European common carp Cyprinus carpio, although this exists in a number of varieties.

Trout

Ponds generally have an intake and an outlet. With the general requirement for clean, well-oxygenated water, inflow of water into the pond is continuous, which also prevents the accumulation of waste products. However, the outlet can also mean that there is a continuous discharge of waste water into the river which supplies the intake. The waste will be similar to that of species in cage culture, i.e., particulate organic material, inorganic nitrogen and phosphorous compounds as by-products from feeding. Discharge into the river is from a point source, which, upon discharge, starts to mix and become more dispersed. However, decomposition of the **particulate organic material**, if sufficiently substantial, will use oxygen and decrease the ambient oxygen concentration for the local communities in the river giving **impacts in the benthic region**. If the load of particulate material is heavy, the receiving water can become anaerobic – although discharges from aquaculture rarely if ever reach this degree of loading. Nevertheless, typically lower oxygen concentrations do affect the local communities, particularly the benthic species, reducing biodiversity and favouring pollution-tolerant types such as chironomid larvae.

Increases in the **soluble inorganic nitrogen and phosphorus** below the discharge point changes the water quality and can stimulate the growth of aquatic plants. This enriched water quality may change the species composition of the river and encourage growth of types that limit water flow and interfere with re-aeration. In addition, in transporting these plant nutrients downstream, they will add to the overall trophic status in the river system. In order to preserve the nature and trophic status of the original river as far as possible, regulators often limit the quantities of nitrogen or phosphorus that can be discharged from a farm. Since this is largely derived from the proteins of the feed, it limits the biomass that can be produced.

The **need for a relatively high water flow** requires a significant demand and water usage will be in completion with that of other water users and a threat to the river biota. This causes particular problems during the seasonal low-flow periods.

Some of the particulate material may sink to the bottom of the pond and require cleaning out at the end of the production cycle. Given the rapid circulation of water in trout ponds, this is rarely an issue for trout ponds. However, sludge treatment is more of an issue for carp.

Whilst more secure than suspended cages, **ponds are susceptible to escapes** during storms and high rainfall events. The rainbow trout is quite adaptable and will produce viable wild populations. However, it has not become invasive, bearing in mind it was first introduced more than 100 years ago, nor particularly competitive with the native brown trout. In terms of genetic conservation, being of a different genus to the native Salmo viable **hybridisation and introgression have not been an issue**.

Trout ponds are very open to predation from high-profile predators such as herons, kingfishers and otters. Farmers put much effort into protecting ponds with nets or scaring devices. These may **entangle the predators** and cause incidental mortalities. Species impacted are often considerd iconic and sometimes also listed as threatened by the International Union for Conservation of Nature (IUCN) red data list. Entanglements could therefore threaten predator populations and have a major negative effect on public opinions of pond aquaculture.

Carp

Unlike trout, carp do not require a continuous supply of well-oxygenated water. Consequently, there is no through-flow of water and the pond discharges into the water catchment area very rarely or never. Consequently, the suspended solid waste is retained as sludge in the bottom of the pond along with the inorganic nitrogen and phosphorus. There is therefore minimal impact on the potential receiving waters. The sludge, however, remains highly enriched and hence **sludge management is a significant factor**. From time to time the sludge is cleaned out and the pond is left fallow but there is a question of how the sludge is dealt with because dumping in the catchment area may allow the soluble component to leach into the ground water, itself a potentially damaging impact. The sludge must therefore be properly processed. Aeration of the sediment helps because decomposition of the organic component can be completed aerobically, hence the value of a fallow period in the natural cycle of the pond. It is reported that carp ponds in Germany are **net phosphorus sinks** and more phosphorus is removed than added to the system, which would be a positive impact.

Another positive impact is that carp farms appear to **increase and support biodiversity** by taking over the role of wetlands. The farms and their ponds support amphibians, non-predatory mammals and insects, which would otherwise have disappeared from the area. The relatively low-technology and low-input basis of carp farming will support this.

Conversely, as with trout ponds, carp farmers have the **problem of predator control**, principally from fish-eating birds and mammals. The ponds are protected by nets and, in some cases, farmers will kill these predators. Given the conservation status of many of the effected species, and their iconic nature, this could threaten predator populations and have a major negative effect on public opinion of pond aquaculture.

As with trout, carp receive artificial feed. However, being omnivores, they require much less of the high-grade animal protein, essentially fish meal, in their diet. As such, carp farming puts much **less pressure on the wild stocks of the forage fisheries** and, in fact, diets are available in which all fish meal has been replaced.

The semi-natural nature of the ponds and particularly the aerobic decomposition of sludge raises the **issue of CO_2 emissions**. As with other wetlands, it is evidenced that carp farms do contribute, to a small extent, to natural CO_2 emissions.

4.4 Aquaculture type: recirculating aquaculture systems

Below is summarised the major impacts of finfish recirculating aquaculture systems according to the scientific literature and the key expert consultations undertaken in this project (Table 6). Information is draw from the relevant literature review (see section 3.1.4.3) and case studies (see sections 3.2.2.7 and 3.2.2.8).

Table 6: Summary of impacts from recirculating aquaculture system finfish culture

Impact	Scientific literature	Key expert
Positive impacts		
Income	✓	✓
Employment	✓	✓
Healthy products for consumers		✓
Increased seafood consumption		✓
Reduced water consumption	✓	
Negative impacts		
High energy costs	✓	✓
Solid organic waste		✓
Land area use conflict		✓

4.4.1 Socio-economic impact

Since 2004, semi-intensive RAS in the form of MTFs have been applied in Denmark to increase the domestic production of rainbow trout while complying with the EU Water Framework Directive. Subsequently, more farms were established and today the Danish production in MTFs constitutes 15 070 tonnes per year, corresponding to approximately 46 % of the total Danish freshwater rainbow trout production.

MTFs have supported the structure and development of the aquaculture sector in Denmark. Based generally in rural areas outside larger cities, the industry is **important for employment and job creation** (directly and indirectly, including spin-off businesses) and economic activity in relevant areas. Also, the case study identified the **provision of healthy seafood** and the contribution to increased seafood consumption, quality, and diversification in products available as important contributions. Although all MTFs have been at the same location for many years, and despite that fact that the areas belong to the farmers, it is still an important issue that they are typically situated in or next to areas of high landscape value causing **potential conflicts of interest and accessibility**.

Within the last 10 years, a few high-intensity RASs for rearing Atlantic salmon full-cycle from eggs in freshwater to market-size harvest in saltwater have been constructed and more are under way. Farming sole in RASs is a relatively new industry that is still under development, with systems in Spain, Portugal, France and Iceland. The aim is to produce 5 000 tonnes per year within near future (Bjorndal *et al*., 2016).

The Portuguese case study shows how RASs potentially have a positive impact on the economy, as RAS maintenance requires a broader range of suppliers than any other type of production. Because of their controlled conditions, the RASs allow the production of different species in marketable quantities. Sole production **contributes to market diversification**, mainly in terms of supply throughout the year. There is, however, the issue of production costs versus the market value of fish. Often production costs are higher than financials benefit (sales revenues) due to mortalization and high energy costs. In addition, RAS are often financially loss-given or hardly profitable if the **cost of electricity is very high** – as is the case in Portugal – making large investments in colder or warmer water species unfeasible *a priori*, because of the thermal balance needed to optimise the production of species.

4.4.2 Environmental impacts

RASs operate in a more or less closed loop with no direct discharge into receiving waters and the wider environment. As such, the possibilities of negative influences are very limited. All inputs required by the fish are kept within the loop as far as possible. The only output that is required, apart from the harvested fish, is any waste water, and the sludge that accumulates in tanks and filters, as well as nitrogen emissions through the air. **Sludge disposal** is currently considered the major potential negative impact: if sludge were disposed of irresponsibly, there would be possibilities of the associated adsorbed compounds, such as phosphate or medicines, leaching into soil and water within the catchment. In Danish model farms the sludge is laid out in a sludge bed and then put over vegetated wetland treatment areas; however, some part-treated material overtops into natural receiving waters. Although it is reported to be not highly enriched, the fact remains that accumulated sludge is a potential negative impact.

As with all closed systems RAS generally has a relatively **high energy requirement** to drive the circulation and the control systems. This raises the issue of energy efficiency and emissions. The case studies report that RASs consequently have a larger carbon footprint than more extensive forms of aquaculture.

In addition to **competition for land**, resulting from being a land-based facility, there may be additional knock-on negative impacts on visual appeal and amenity value, and potentially the environmental conservation value of the land on which pond culture sites are built.

There are positive aspects to an RAS compared to more extensive pond culture. **Water use is much lower,** which also means that water supply structures such as dams across natural water courses are not required. Water for RASs often comes from pumped ground water, putting them in competition with other ground water users.

4.5 Aquaculture type: integrated multi-trophic aquaculture

Below is summarised the major impacts of integrated multi-trophic aquaculture according to the scientific literature and the key expert consultations undertaken in this project (Table 7). Information is draw from the relevant case study (see section 3.2.2.9).

Table 7: Summary of impacts from integrated multi-trophic aquaculture

Impact	Scientific literature	Key expert
Positive impacts		
Potential contribution to future sectoral growth		✓
Reduced solid and dissolved waste	✓	✓
Offsets some impacts of monoculture culture	✓	✓
Negative impacts		
Cumulative impacts of polyculture		✓

4.5.1 Socio-economic impact

Systematic economic data collection on IMTA does not take place in the absence of substantial commercial IMTA farming. This is reflected in the Portuguese case study, where IMTA is seen as one of the **solutions to stagnation in growth** of the aquaculture sector. However, as of now there are no companies that do commercial IMTA farming because there is perceived to be no prospect of an economic return at present, presenting a major obstacle to growth of this technology. Further research for this assumed lack of business case is needed.

4.5.2 Environmental impacts

The principle of IMTA is the mixing of species in which some species use the outputs of other species, such as waste products, to **add to their productivity**. For example, salmon may be grown in conjunction with macroalgae such that the algae use the soluble, nutrient-rich waste from salmon excretory products (nitrogen and phosphorus components) for rapid photosynthesis and growth, which, when the algae are harvested, **removes these excess nutrients from the water body**. Similarly, if salmon are grown over a culture of deposit-feeding clams, the clams are able to use the sediment carbon-rich particulates, thereby regulating the carbon turnover in the ecosystem at harvest.

In principle, the integrated system is **subject to the negative impacts of all the components**. However, the principle essentially means that the negative impacts of **some components are offset by the positive impacts of others, such as denitrification**. However, there can be impacts linked specifically to the multi-trophic nature of the culture, which is linked to getting the balance between the components correct – always a problem with polyculture. For example, the area of kelp production necessary to offset the utilisation of all inorganic excretory products produced by the salmon farm above the kelp can be relatively extensive and can run into regulatory problems as a result. Currently, obtaining regulatory approval for IMTA systems remains a problem.

4.6 Aquaculture type: shellfish

Below is summarised the major impacts of shellfish tray, suspended and, bottom aquaculture according to the scientific literature and the key expert consultations undertaken in this project (Table 8). Information is draw from the relevant literature review (see section 3.1.4.4) and case studies (see sections 3.2.2.10, 3.2.2.11, 3.2.2.12, 3.2.2.13, 3.2.2.14, and 3.2.2.15).

Table 8: Summary of impacts from shellfish culture

Impact	Scientific literature	Key expert
Positive impacts		
Income	✓	✓
Employment	✓	✓
Gender equality	✓	
Water quality	✓	✓
Denitrification	✓	✓
Biodiversity	✓	✓
Negative impacts		
Labour conditions		✓
Conflicts with other users of coastal space		✓
Impact on species communities	✓	✓
Seston depletion	✓	✓
Solid organic waste	✓	✓
Sedimentation	✓	✓
Disease	✓	✓
Wild spat collection	✓	✓
Genetic introgression (spat)	✓	✓
Health of wild predatory species		✓

4.6.1 Socio-economic impact

According to the data reported to FAO, the **EU represents approximately 25 % of world production of blue and Mediterranean mussel**, both in volume and value (FAO, 2019). However, it is known that some countries do not report production per species, instead opting to refer to the country of production (e.g., Chilean mussel).

According to data collected under the DCF for the year 2018, the volume of mussels produced in the EU is 485 000 tonnes (including other non-DCF data), valued at EUR 447.8 million. In total, 93 % of the companies reported under the DCF/EU-MAP area are concentrated in six countries: Spain (63 %), France (11 %), Italy (7 %), Greece (6 %), United Kingdom (3 %) and Croatia (3 %). The average wages differ significantly between countries, which can be seen as an indicator of technological and organisational development in the various countries.

In 2017, European sales of clams were almost 45 000 tonnes, with a turnover of EUR 205 million. In 2018, the production decreased by 14 % in volume compared to 2017, with a turnover of EUR 181 million, corresponding to a 12 % reduction. Four EU countries produce clams: Italy (81 % of EU production), Portugal (9 %), France (7 %) and Spain (3 %).

Positive socio-economic impacts mentioned in the Spanish case study include **employment in aquaculture** and employment in the seafood processing industry.

In the Netherlands, positive economic and social impacts include employment in aquaculture and the fish-processing industry and **increased international trade**. The fact that the mussel industry in Yerseke has a central role in the processing of blue mussels in Northern Europe creates opportunities to supplement national production with additional imports. Negative economic and social impacts identified are **conflict with other uses of the coastal zone**. Health and safety of workers using mussel seed collection devices (MSCDs) are mentioned: working with MSCDs is associated with **hard working conditions** such as increased work pressure and long working hours per day.

Current production of blue mussels in Ireland has a value of around EUR 13 million, of which rope-grown accounts for around EUR 6 million (Bord Iascaigh Mhara, 2021), and contributes approximately EUR 3.03 million in wages and salaries to workers (STECF 20-12). The major positive impacts of blue mussel aquaculture in Ireland are primarily social and economic. The aquaculture sector is an **important employer and economic support in rural coastal regions** of Ireland, where it supports traditional Irish-speaking cultures and communities. The sector may be an important contributor to reducing unemployment rates and **combating poverty for low-skilled workers**, particularly in rural areas where employment options are often more limited.

The Portuguese case study on clams and oysters highlights significant contributions to the fishing communities of the Rias Formosa and Aveiro lagoons. At the local level in Ria Formosa the livelihoods of more than 10 000 people are directly and indirectly related to mollusc farming activity, which corresponds to a **large positive economic impact**. Ria Formosa contributes a very high percentage to the production of bivalve molluscs: in the order of 80–90 % (INE, 2020 & 2021).

At a social level, culture of clams and oysters requires skilled labour. Until about 10 years ago, this workforce also remained stagnant. Younger labour did not come in because the activity was synonymous with a lot of physical work and relied heavily on harmful environmental factors over which the producer has no control. In terms of gender equality in mollusc farming itself, women have more of a role in collecting juveniles in natural banks and men clean the *viveiros* (inshore, man-made culture beds, and offshore systems like long lines and rafts). Over the last 10 years, many young people have begun to show interest in this sector, and are trying to improve their roles in terms of labour and production. Hence, there is currently a very different awareness and way of working.

4.6.2 Environmental impacts

Clams and oysters

Oysters can be grown in planted beds on the sediment, supported structures or trays or racks in intertidal areas. The latter system predominates in France, one of the major European producers. Clams are reared in similar rack systems although some clams may be 'ranched' from managed beds on the sea bottom, as seen near Venice at the head of the Adriatic – rather as mussels are in the Netherlands. In addition, in the late stages of the production cycle, oysters may be moved to shallow ponds for fattening on the rich plankton that develops in these brackish ponds.

Oysters are filter feeders. When a large biomass is being cultured in the natural marine system, oysters may **take a high proportion of the phytoplankton** to the extent that there is **insufficient to support other filter feeders** in the natural communities in the same water body. Cases of overstocking and consequent overexploitation of plankton have been reported in France. The potential negative impact on the surrounding ecosystem can, therefore, be significant. Clams can equally be filter feeders although a number of genera are deposit feeders, which profit from the enriched sediment.

The historic role of the oyster industry in the global spread of nonindigenous species, biofouling pests, toxic or noxious microalgae, and disease is well-recognized (Ahmed & Salomon, 2016). The Pacific oyster itself can be an invasive species, especially in rocky habitats and on artificial structures but there is also evidence that they can invade soft-sediment estuarine habitats.

The by-products of filter feeding accumulated as sediment below the racks and the oyster culture may filter a high proportion of the water in the water body with the result that the higher deposition rates below the racks is matched with lower sedimentation rates elsewhere in the water body thus altering the dynamics of the carbon within the water body. The **sediment accumulating** under the culture racks enriches the underlying sediment but hinders oxygenation causing a shift to more anaerobic respiration in decomposition, which is reflected in the disappearance of more sensitive species, such as the heart urchin Echinocardium to a greater abundance of pollution-tolerant species such as the polychaete *Capitella*. Consequently, oyster farming on racks can have wider effects on the ecosystem although the significance will depend upon the extent of the farming activity and the hydrology and flushing characteristics of the locality.

Traditionally, oyster seed for the trays is taken by using collectors with hard settlement surfaces from wild populations. This may be an issue if the oysters mature in culture and release their gametes into the sea in the vicinity of the farm. If the **wild source has a different genetic composition to that of populations near the farm**, there is a possibility of the local strain being compromised. This effect is accentuated if more than one species is involved, since inadvertent collection of other species can increase the spread of that species. For example, there are three species that have been widely used for farming in France: the native European oyster *Ostrea edulis* and two introduced species – *Crassostrea angulata* and *Crassostrea gigas*. Although the latter two were introduced specifically for aquaculture, they have formed natural populations that have spread. *Crassostrea gigas* has **attained almost invasive proportions** forming dense reefs on the west coast of France, which cause their own local impacts and are difficult to exploit.

The **control of genetic dispersion** in clams is dealt with by the use of triploid stock, which grow well but are infertile. These triploids are produced in specialist hatcheries, of which there are a number in Europe, and the farmers buy all their seed from these suppliers. Since they are reared in hygienically controlled conditions, they are disease free. Hence, even though they may be transported long distances they are very unlikely to spread diseases. This method also greatly reduces the risk of significant impacts, since translocation of these bivalves does not only lead to genetic issues but also adds to the spread of disease. A number of severe epidemics amongst both cultured and wild populations have damaged the industry, highlighting a potential major issue in terms of biosecurity and health control. This has been compounded in some cases where exotic diseases have arrived in the country and spread rapidly to vulnerable local populations. The purchase of **disease-free stock** greatly reduces the risk in clams and, increasingly, in oysters. Increasingly, seed is obtained directly from hatcheries.

In addition, there is a potentially positive impact from the oysters or clams in that the enhanced biomass will consume an equally high volume of phytoplankton. Since the phytoplankton have consolidated plant nutrients including inorganic nitrogen and phosphorus into their production, the consumption of this and the harvesting of the bivalves will **remove stimulants for algal growth and eutrophication from the**

system. This is the process sometimes termed denitrification although more than just nitrogenous compounds are involved.

The structures themselves do have an impact. They can retard water flow and thereby increase sedimentation and can provide hard surfaces for the settlement of plants and animals. Although some of these are regarded as foulants, the **biodiversity is enhanced in ecological terms**.

When oysters are moved to the **fattening ponds** they are removed from the open environment. There is no exchange between the ponds on the receiving waters. They may receive a top up from the tidal flow, but with no regular discharge the **impacts on the wider environment are negligible**. Within the ponds there are changes as the rich phytoplankton is consumed by the bivalves with recycling of nutrients and accumulation of sludge but this remains within the fattening ponds. As siting is done in history, the impact of landuse is considered consilidated.

The **siting of racks**, if extensive, may cause issues in terms of **changing the water flow** patterns and also as a **hindrance to navigation**. The racks may also be considered unsightly as they emerge at low tide and impact the amenity use of the locality.

Mussels

There are two main methods of cultivating mussels: suspending or supporting them, commonly on ropes, frames or posts; or planting them out in suitable locations on the sea bed. In these extensive methods, inputs are negligible in terms of therapeutant and also feed. Mussels are filter feeders and rely on natural plankton production for nutrition. Consequently, mussel farms tend to be located in relatively productive areas, mostly coastal waters. However, in culture, where there is an artificially high stocking density, the culture must remain within the productive capacity of the ecosystem otherwise it will negatively affect the availability of plankton for other constituents, particularly filter feeders, of the wider ecosystem.

Although there is no artificial feed, there is still particulate waste coming from the filter-feeding process, the pseudo faeces and faecal debris itself. There is thus settlement of organic particles in the benthic area around the farm, which results in **organic enrichment of the sediments**. If sedimentation is intense, then the sediments can become anaerobic with the production of toxic sulphide, as described for marine cage farms. Accumulation of sulphide leads to reduction of biodiversity in the affected benthic region. Clearly, it is likely to be much less of a risk than under cage farms for fin fish with their intensive feeding regimes.

The **seed for mussel culture is typically collected from a wild source** or collection devices using different substrates (rope, net) and, since quite large numbers are required, there is the possibility that the **volumes collected may threaten the sustainability of the source populations**. In addition, since the collected mussel spat will be moved away to the production area, there is the possibility that the wild stock in the vicinity of the farm may be of a **different genetic composition**. This could risk the genetic constitution of the wild stock if the cultured individuals survive to release their reproductive products into the sea.

The transport of seed and brood stock between locations raises a threat to biosecurity and spread of disease. **Disease** is always a problem when a large number of individuals are kept together in culture. Mussels, as with other shellfish, are quite susceptible to a number of diseases. It is particularly difficult for bivalves because of their rudimentary immune system, they appear to have limited resistance and also there are virtually no therapeutants to mitigate the risk. The only practical methods are strict biosecurity regimes that involve restricted and controlled translocation of seed and grown mussels.

Large densities of mussels, or any bivalve, attract a wide variety of predators such as crabs, starfish, fish, rays, predatory snails and diving ducks. This will only have real impacts on the ecosystem if the farmers use lethal measures to eliminate them. . In these cases, there may be **threats to some of the predatory species**, particularly those with a vulnerable conservation status.

Bottom culture of mussels requires large areas of sea bed to be planted with seed mussels, which clearly takes a significant part of the natural ecosystem. This can be regarded as a negative impact on ecosystem structure. In addition, harvesting mussels cultured on the sea bed, as in the Waddenzee, disturbs large area of the sea bed and generates large plumes of sediment behind the harvesting vessel. This sediment settles over the surrounding sea bed, smothering the communities and also increases turbidity in the water thus cutting down light availability for primary production in the pelagic zone. Nevertheless, these benthic communities are adapted to withstand occasional storms that churn up the sea bed and it has been noted that planted mussel bed areas, over the long term, are actually **more diverse** than non-planted areas (DeAlteris *et al*., 2004).

Siting for suspended mussel culture is not as intrusive, but the tendency for organic settlement below the structures does mean that **sensitive habitats and communities below the farm, such as sea grass beds, could be damaged**, scale, density, hydrodynamics, and ecosystem state are important factors of influence.

Regarding other aspects of biodiversity, the proliferation of hard surfaces in support structures and the mussel shells themselves can provide for attachment of sessile animals and plants as well as shelter for mobile crustaceans such as crabs, thereby **increasing biodiversity**.

4.7 Aquaculture type: macroalgae

Below is summarised the major impacts of macroalgae aquaculture according to the scientific literature and the key expert consultations undertaken in this project (Table 9). Information is draw from the relevant literature review (see section 3.1.4.5) and case studies (see sections 3.2.2.16 and 3.2.2.17).

Table 9: Summary of impacts from macroalgae culture

Impact	Scientific literature	Key expert
Positive impacts		
Income	✓	✓
Employment	✓	✓
Biodiversity	✓	✓
Reduce eutrophication	✓	
Carbon fixation	✓	✓
Negative impacts		
Food safety	✓	
Alteration of the benthic community		✓
Conflicts with other users of coastal space		✓
Biodiversity	✓	✓
Sedimentation		✓
Genetic introgression	✓	✓

4.7.1 Socio-economic impact

Cultivation of macroalgae in Europe is an emerging sector. A good dataset on the production volumes is missing. Reports from FAO state that Europes produces 552–tonnes (2019), while current volume has been estimated at around 1 450 tonnes fresh weight based on few used species (Araújo *et al.*, 2021).

Macroalgae aquaculture is developing in several countries in Europe, with France, Ireland and Spain being the top three countries for the number of macroalgae production units. Macroalgae aquaculture allows for **creation of economic growth and jobs in coastal areas**, and offers direct, permanent employment. It also offers the opportunity to develop a new integrated industrial sector with local stakeholders. Macroalgae can be **used in a variety of ways, including for food, feed and biomaterials**.

In general, impacts on **food safety** were considered highly important. The high iodine content of seaweeds could also have adverse effects on human health if consumed in excessive quantities. The scale of the farm and fear of environmental impacts have a substantial effect on the level of acceptance of stakeholders towards seaweed farming activities (Billing *et al*., 2021). Community aversion to seaweed aquaculture is also caused by **conflicts with other activities** for the use of the coastal space.

Billing et al. (2021) highlighted that the socially acceptable part of the seaweed industry in France was perceived as small-scale, with clear environmental regulation and information provision. Contrarily, large-scale production systems were associated with difficulties in enforcing mitigation measures for environmental and social impacts. Scientific literature on offshore seaweed farming discusses the high costs and need to reduce these for profitable offshore seaweed farming (Bak et al., 2018).

4.7.2 Environmental impacts

There are basically two ways of producing seaweeds (macroalgae): harvesting natural grown beds or by attaching new propagules to hard surfaces, natural or otherwise, for new growth. In Europe, currently, the former tends to predominate – although with the recent upsurge in interest in algae and algal products, more ways will be tried.

In harvesting, the target seaweeds through their structure, provide habitats for a variety of, principally sessile, animals and plants and essentially underpin the whole ecosystem structure and function. Harvesting needs to be within the capacity of the seaweed bed to be sustained to avoid overexploitation of its own population but removal can also have impacts on the habitats of other species that depend upon the seaweed bed as a basis for the ecosystem. That impact could be compounded if species dependent on the bed have a sensitive conservation status. Equally, the removal of the target seaweed species from other macroalgae, which may also be removed or disturbed, may threaten the long-term persistence of these non-target macroalgae in the community and ecosystem. This, in turn, could have further **impacts on biodiversity** and functioning via dependant organisms.

Farming seaweeds **requires few inputs from therapeutants, chemicals or otherwise** (some intensive close-system cultures do use fertilisers) thus there are few impacts on the surrounding water. If moribund seaweed is allowed to accumulate during the harvesting process, some local deoxygenation is possible.

Seaweed beds may reduce current flows and therefore **sedimentation** of particulates, thereby somewhat enriching the organic content of the benthic sediment although rarely to a point where significant negative changes occur.

Where seaweed beds are planted out as propagules and when new strains of the seaweed species are brought in from elsewhere there can be impacts on genetic conservation. Although seaweeds are attached and sessile, their reproductive products are released into the water where fertilisation takes place. Consequently, the reproductive products of the new strain can be mixed with those of the local strain with the possibility of less-fit mixes occurring. In such cases, it will be important to use propagules with an equivalent genetic makeup to that of the local strain; however, the limits of genetic types within seaweed populations and localities are not currently well-known. **Genetic dispersion** in this way has the same potential impacts as escapes in finfish. The same is also the case if the planted material is from a different species. This presents the risks of potential hybridisation and also spread of an exotic species with the possibility that it may become invasive. An example is wakame Undaria pinnatifida, originally introduced on the west coast of France for aquaculture but which has now become widespread generally along the coast.

One positive impact of extensive farming of seaweed beds is the potential **removal of stimulants to eutrophication**. In photosynthesis the algae incorporate inorganic nitrogen, phosphorus and carbon from the water into their tissues. At harvest these are removed from the system, thus providing some control on the trophic status of the water. The use of carbon, in the form of CO_2, to some extent enhances the capacity of the ocean to be a **carbon sink** in the control of emissions.

4.8 Aquaculture type: microalgae

Below is summarised the major impacts of microalgae aquaculture according to the scientific literature and the key expert consultations undertaken in this project (Table 10). Information is draw from the relevant literature review (see section 3.1.4.5) and case studies (see sections 3.2.2.18 and 3.2.2.19).

Table 10: Summary of impacts from microalgae culture

Impact	Scientific literature	Key expert
Positive impacts		
Use of marginal lands	✓	✓
Health products for consumers		✓
Waste water treatment	✓	✓
Carbon fixation	✓	✓
Negative impacts		
Occupational hazards, dealing with chemicals		✓
Solid organic waste		✓
Eutrophication (accidental release)		✓
Invasive species (accidental release)		✓

4.8.1 Socio-economic impact

A detailed overview of the European production (EU-27, United Kingdom, EEA countries and Switzerland) is provided by Araújo *et al.* (2021). Germany, France and Spain host the largest number of microalgae producers in Europe. Based on the production capacity, the largest microalgae production plant in Europe is located in Klötze/Germany and was designed for an annual production of 60–100 tonnes dry weight. The same countries (together with Italy) have the largest number of Spirulina producers. However, France dominates the production landscape, with 65 % of the mapped production units in Europe. Microalgae and Spirulina production is located mainly on inland sites. In total, 76 companies producing microalgae have been identified in 16 countries in Europe along with 222 companies producing *Spirulina* spread across 15 European countries. Microalgae still represent a niche market, although with highly increasing market growth in recent years. Worldwide production volume is estimated at 56 456 tonnes (FAO, 2021).

Key experts mentioned mainly positive socio-economic impacts of microalgae cultivation, primarily: the possibility of the **microalgae production on marginal land**; the integration of the production process and parts of it, respectively, in bio-economy strategies (biorefineries, coupling processes, etc.); **health aspects for consumers** when microalgae are used as functional food/nutraceutical; and economic opportunities for microalgae in a diverse range of markets. Potentially negative aspects related to occupational health and safety include **the safety risk when handling chemicals as feed input** for microalgae growth.

4.8.2 Environmental impacts

The culture of microalgae can be either extensive in open ponds, or intensive in closed recycling units. In both cases **discharges** into the wider environment are intentionally very limited. Although nutrients are required for the growth of the algae, they are intended to remain within the system – mainly in the growth of the algae, which is harvested at the end of production. Significant discharges tend to be mainly accidental. Even so, the algae used tend to be amongst those associated with eutrophic conditions and algal blooms so their release into the environment would be a threat, more so if the alga was an exotic species for the area.

The main potentially negative impacts are from **waste water** and sludge from the bottom of ponds or from filters as well as any organic waste from the processing to the final product. Impacts would only be evident if the sludge were to be dumped where it could leach into water courses, as is also the case for impacts from nutrient rich waste water. However, the waste water can be readily treated in **water-treatment plants and sludge can be recycled**, for example as organic fertilizer in agriculture.

The production plants themselves, particularly the extensive pond system, does have a requirement for land to an extent not evident in other forms of aquaculture. Because of this, the culture of microalgae could compete with agriculture. However, because the land required does not have to be fit for agriculture production, **marginal or reclaimed land** can be used albeit subject to its not intruding into conservation areas or land of a protected status. Loss of amenity value can also be avoided.

To promote circulation within the system and control does require energy, so there is a potential issue of **energy efficiency and emissions**, which can be considered an impact. These impacts could be mitigated by the use of renewables such as wind or solar power and aquaculture could be developed in conjunction with generators such as wind farms.

The culture of microalgae can have some positive impacts. There is the possibility of integration with waste water treatment by using the inorganic components for growth and also using atmospheric CO_2 to **fix carbon** in their production.

5 THE REGULATORY FRAMEWORK FOR AQUACULTURE IN THE EU

Task 3 called for a review, as part of each case study, of the existing regulatory framework for aquaculture and the mitigation measures implemented (when possible) for the existing negative impacts, in order to try to assess whether or not the regulatory framework has had any effect on the impacts (i.e., whether some have proved effective in mitigating negative impacts).

5.1 The complexity of the regulatory framework for aquaculture in the EU

The regulatory framework for the aquaculture sector in the EU is diverse and extremely complex. It includes a wide range of instruments adopted at the EU level as well as Member State legislation. In addition, site-specific measures to address negative impacts are usually contained in the specific licence conditions of each individual aquaculture facility.

This complexity arises for three main reasons. First, there is the sheer diversity of the aquaculture sector itself in terms of: (a) the types of species cultured; (b) the types of water in which aquaculture is undertaken (freshwater, seawater or brackish water); (c) the types of aquaculture technology used; and (d) the scale of aquaculture production. Different legal rules may apply depending on each of these factors. For example, different rules apply to the cultivation of aquatic animals in comparison to the cultivation of aquatic plants, or to freshwater aquaculture compared with marine aquaculture and so on.

Second, apart from legislation that has aquaculture as it's specific focus (which can be described as ‘aquaculture legislation’), aquaculture takes place within, and is subject to the rules of, a much broader legal framework (the ‘overall legal framework for aquaculture’) that addresses such matters as land-use planning/development, maritime spatial planning, navigation, coastal zone management, environmental impact assessment, aquatic animal and plant health, feed, medicines, chemicals, employment and health and safety issues, environmental protection (including that relating to water quality and biodiversity), food safety, and traceability and animal welfare.

The final reason for the complexity of the legal framework concerns the scope and nature of EU legislation on the topic and its relationship with Member State legislation. Unlike the case of marine capture fisheries, aquaculture is not an exclusive EU competence[5]. This is why the Basic Regulation on the Common Fisheries Policy[6] provides, in article 1 (1)(b), that the scope of the common fisheries policy applies to aquaculture only in relation to measures on markets and financial measures in support of the implementation of the Common Fisheries Policy (CFP). This also explains why the Basic Regulation on the CFP itself contains relatively few substantive provisions on aquaculture. Part VII, with its single article (article 34) entitled ‘Promoting sustainable aquaculture’, sets out a method of strategic coordination based on strategic guidelines adopted by the European Commission and multi-annual national strategic plans translating those guidelines into the concrete reality of the sector in each Member State. The European Commission facilitates the exchange among Member States of good practices at national level in implementing those plans under the so-called ‘open method of coordination’. Article 42 of the Basic Regulation on the CFP provides for the establishment of the Aquaculture Advisory Council to make recommendations on aquaculture policy to the European Commission. Beyond these provisions, relatively

[5] More specifically, in accordance with article 3 (1) of the Treaty on the Functioning of the European Union (TFEU), the EU has exclusive competence with regard to the conservation of marine biological resources in accordance with the CFP.

[6] Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC (OJ L 354, 28.12.2013, p. 22).

little aquaculture-specific legislation (in other words, aquaculture legislation in the sense used above) has been adopted at EU level.

At the same time, as will be seen, the EU has legislated extensively on most of the aspects of the overall legal framework for aquaculture, generally in the form of: (a) Regulations, which are directly applicable at Member State level; and (b) Directives which must be transposed into national law by the Member States.

At the Member State level, aquaculture legislation forms the primary regulatory instrument for the sector, either in the form of a specific aquaculture law, as in the cases of Croatia[7], Greece[8], Portugal[9] and Spain[10], or a chapter in a fisheries law as in the case of Ireland[11], or a fisheries and aquaculture law as in the case of France[12]. Sometimes, specific legislation applies to different types of aquaculture, such as the *Bekendtgørelse om Modeldambrug* or 'Executive Order on Model-Trout-Farms' described in the Danish case study. Such aquaculture legislation typically creates a licensing framework for individual aquaculture facilities.

At the same time, Member State legislation on other aspects of the overall legal framework for aquaculture either gives effect to obligations under EU law (often through the transposition of obligations imposed by directives) or it may address issues that are not addressed by EU law (such as land-use planning). Such legislation in turn interacts with the aquaculture legislation and its implementation – sometimes because it sets out procedural steps to be followed before an aquaculture licence can be issued (such as a requirement for an environmental impact assessment) and sometimes because it informs how the aquaculture legislation is to be implemented by, for example, identifying areas in which aquaculture may or may not take place or by providing the basis for specific conditions in aquaculture licences that seek to ensure the achievement of environmental objectives.

5.2 Approach to this task

A review of the existing regulatory framework and mitigation measures was undertaken as part of each case study under Task 2. Each case study was undertaken by a national consultant or consultant team on the basis of desk research and a series of semi-structured interviews with key experts from national authorities and national research institutes in the countries where case studies were conducted, as well as some industry members of the Aquaculture Advisory Council (speaking in a personal capacity) who addressed impacts across the EU rather than at the case study level.

In order to support both information gathering and analysis, all of the known potential negative social and economic impacts of aquaculture were first systemically identified and set out in table form with the relevant EU legislation (if any) adopted to address that impact included in a separate column. The table was based on the 'Aquaculture Law Assessment and Revision Tool' (ALART), currently being developed by FAO, in that it follows the logical order of aquaculture development starting from site approval through to post-production impacts. A separate review was prepared for each case study, and these reviews are included in the case study reports attached as Annex 3.

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7 Law on Aquaculture, No. 130/2017.
8 Law on Aquaculture Development, 2014.
9 Decree-Law No 40/2017.
10 Law 23/1984, of June 25, on marine farming. In Spain the legislative framework is further complicated by the high degree to which law making is decentralised to the Autonomous Communities in accordance with the Constitution. Similarly, the overall framework for aquaculture in Germany comprises a mixture of federal and lander laws.
11 Fisheries (Amendment) Act 1997.
12 Law No.97-1051 on Maritime Fisheries and Mariculture.

5.3 The approach of the regulatory framework for aquaculture to the mitigation of negative impacts

5.3.1 Negative impacts as a result of the siting of aquaculture facilities

In practice, the main potential negative social and environmental impacts from aquaculture result from the inappropriate siting of aquaculture facilities. A range of regulatory measures adopted at EU and Member State level seek to address this issue.

5.3.1.1 Negative impacts from the siting of land-based aquaculture facilities

Negative social impacts may arise from the siting of aquaculture facilities on land (such as ponds, tanks and raceways as well as RASs) in terms of the loss of amenity value, conflicting land uses, a loss of landscape values as well as inappropriate siting in terms of general development objectives/zoning for particular uses. At the Member State level, these issues are addressed in land-use planning laws, which in some cases also apply to maritime waters in the nearshore area. The issue of land-use planning is not directly addressed in EU law[13] although, as will be seen below, the environmental impacts of new development projects, including aquaculture, may be. For example, in Croatia the Law on Spatial Planning sets out the minimum content of spatial plans at the national, regional and local level. Seven coastal counties of Croatia have adopted spatial plans with defined zones favourable for aquaculture activities. These spatial plans focus on the marine area, while only the Dubrovnik-Neretva County plan includes the coastal area for fish farming support, such as an aquaculture research and development centre and other facilities needed to support aquaculture.

5.3.1.2 Negative impacts from the siting of marine aquaculture facilities

Negative social impacts may arise from the siting of aquaculture facilities in maritime waters in near-shore or offshore areas. Such impacts may include conflict with other uses of the sea, as well as inappropriate siting in terms of general development objectives/zoning for particular uses.

At the EU level, the Maritime Spatial Planning Directive[14] (MSP Directive) requires EU Member States to adopt the necessary legislation to provide for establishment of 'maritime spatial planning' to 'identify the spatial and temporal distribution of relevant existing and future activities and uses in their marine waters' and to adopt the necessary implementing legislation accordingly. Article 8(2) of the directive sets out an indicative list of maritime activities that must be taken into consideration in the development of maritime spatial plans. This list begins with 'aquaculture areas', followed by 'fishing areas', and a range of other activities including 'maritime transport routes and traffic flows' and 'nature and species conservation sites and protected areas'.

At Member State level, as already seen in the case of Croatia, land-use planning legislation and related land-use plans may also apply to the coastal waters of the country concerned. The spatial plans in Croatia define aquaculture zones as A1, A2 and A3 according to the priorities, spatial conflicts and micro-location suitability for the aquaculture production. A1 zones are prioritised for aquaculture and while other economic activities may be permitted there, such activities must not be harmful for

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[13] This is because in accordance with article 192(2)(b) of the Treaty on the Functioning of the European Union (TFEU)(OJ C 326 26.10.2012, p. 47), while legislation on other aspects of environmental policy can be adopted in accordance with the ordinary legislative procedure on the basis of a qualified majority vote in the Council, measures on inter alia town and country planning and land use (with the exception of waste management) can only be adopted with the Council acting unanimously in accordance with a special legislative procedure and after consulting the European Parliament, the Economic and Social Committee and the Committee of the Regions.

[14] Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning (OJ L 257, 28.8.2014, p. 135).

aquaculture. The A2 zone allows the coexistence of aquaculture and other activities with priority being given to aquaculture, while in A3 zones aquaculture is considered least desirable. In that way conflicts over the maritime space are reduced.

Another approach, set out in Greece's Law 4282/2014 'Development of aquaculture and other provisions', is to establish a specific spatial planning mechanism for aquaculture through the establishment of Allocated Zones for Aquaculture (AZAs) (Organized Aquaculture Development Areas in Greek – POAY) in the framework of the implementation of the Special Framework for Spatial Planning of Sustainable Development of Aquaculture (SFSPSDA). The SFSPSDA was established on the basis of Joint Ministerial Decision No 31722/2011, FEK 2505, ratified on 4 November 2011, which set out guidelines, directives and criteria for the development of aquaculture, aiming to ensure protection for the environment and the competitiveness of the sector. Ten years later, however, only three out of the 23 proposed AZAs have passed the controls of the Council of State (the Supreme Court of Greece), meaning that it is anticipated that the respective Presidential Decrees will be signed soon. The fate of the remaining 20 AZA plans remains vague.

At the same time, siting is an issue that is invariably taken into consideration in the licensing of aquaculture facilities. For example, in Ireland the ability of an aquaculture facility to withstand the weather and other environmental conditions, and to avoid damage that may result in escapes, is a factor that is taken into account during the licence determination procedure.

5.3.1.3 Negative impacts relating to navigation

Potential negative impacts from the siting of aquaculture facilities could include the obstruction of navigation routes, both at sea and in rivers/estuaries, as well as the fact that such facilities may also constitute navigation hazards. In terms of EU legislation, as already seen, 'maritime transport routes and traffic flows' are maritime activities to be taken into consideration in the development of maritime spatial plans under the MSP Directive. The case studies suggest that at Member State level this issue is typically addressed through a combination of aquaculture legislation and navigation legislation whereby the aquaculture legislation requires the approval of the relevant harbourmaster/navigation authorities and other relevant bodies before the issuance of: (a) a concession, lease or other right to use the seabed for aquaculture purposes; and/or (b) an aquaculture licence. For example, article 9 of Spain's marine aquaculture law explicitly cross refers to the need for approval from the competent bodies responsible for matters of defence, the safety of navigation, and ports and coasts prior to the authorisation of new mariculture facilities.

5.3.1.4 Negative impacts from land degradation

Certain types of land-based aquaculture facility may cause salinisation and other types of land degradation. This may be of particular concern in cases where aquaculture facilities are constructed on public land. This issue is not addressed in EU law. Instead, it is addressed, if at all, at Member State level in the relevant aquaculture legislation by requiring licence holders to provide a bond to ensure site clean-up or insurance. For example, article 22 of the Portuguese aquaculture law requires the provision of a security deposit on the issuance or transfer of an aquaculture licence in order to ensure that when the licence ends, the site is left in a good environmental state and 'works and structures' are removed. Such a deposit may be provided through, for example, a bank deposit, a bank guarantee, a financial guarantee or equivalent financial instrument.

5.3.1.5 Negative impacts regarding coastal zone management

Aquaculture, particularly brackish-water aquaculture, often takes place in the low-lying coastal zone, an area that can be vulnerable to storm surges, often highly populated and provides a range of livelihood and vital ecosystem functions. Negative impacts from aquaculture in the coastal zone can include environmental damage in ecologically sensitive/vulnerable areas, conflicts with other uses of the coastal zone and the destruction of lagoons, reefs and natural storm surge/flooding systems. No specific legislation on the coastal zone has been adopted at EU level, although this issue was addressed in a recommendation of the European Parliament and of the Council in 2002[15] which lists eight principles defining the essential characteristics of integrated coastal zone management (ICZM) and outlines steps that Member States should take to develop national strategies for ICZM.

Conversely, some Member States, such as Spain, have adopted specific legislation for coastal zone management and an approval from the authorities responsible for the implementation of the Law on Coasts is one of the requirements for the issuance of an aquaculture licence under the Marine Aquaculture Law.

5.3.1.6 Negative environmental impacts as a result of the siting of aquaculture facilities

As a result of siting decisions, aquaculture facilities may have a number of negative environmental impacts including in relation to siting within or near protected areas, negative impacts on biodiversity, interference with migration paths and siting in ecologically sensitive areas.

This issue is addressed directly or indirectly in a number of items of EU legislation. For example, the EIA Directive[16] provides that an environmental impact assessment (EIA) is required for new projects involving 'intensive fish farming' that are likely to have 'significant effects on the environment'. These terms are not further defined in the directive itself. The Member States have, in transposing the EIA Directive (usually in their land-use planning or environmental legislation), applied a range of criteria in order to determine what amounts to intensive fish farming with significant effects on the environment. These include the size of the aquaculture facility (e.g., requiring an EIA if the size of a proposed aquaculture facility exceeds 5 hectares), the total fish production output (e.g., yearly production higher than 100 tonnes), fish production output per hectare (e.g., carp ponds with a fish production output higher than 4 tonnes per hectare of the pond area) or feed consumption (e.g., more than 2 000 kg of dry feed consumed per year) (European Commission, 2015).

While the EIA Directive is concerned with individual projects, the Strategic Environmental Assessment Directive[17] (the SEA Directive) requires a formal environmental assessment of plans and programmes that are likely to have significant environmental effects. It applies to plans and programmes prepared *inter alia* for agriculture, fisheries, town and country planning or land use and that set out the framework for future development of consent of projects listed in the Annexes to the EIA Directive or that, due to the likely effect on sites, have been determined to require an assessment pursuant the Habitats Directive. Although the directive does not explicitly refer to the sector, aquaculture development plans and programmes will be subject to

[15] Recommendation of the European Parliament and of the Council of 30 May 2002 concerning the implementation of Integrated Coastal Zone Management in Europe (OJ L 148, 6.6.2002, p. 24).

[16] Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (OJ L 26, 28.1.2012, p. 1).

[17] Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (OJ L 197, 21.7.2001, p. 30.

its provisions under the headings of agriculture/fisheries if not town and country planning/land use.

The Birds Directive[18] and the Habitats Directive[19] require Member States to protect particular species and particular habitats through the establishment of Special Protected Areas (SPAs) for birds and Special Areas of Conservation (SACs) under the Habitats Directive. Together, SPAs and SACs constitute Natura 2000, which, under the Habitats Directive, is designed to comprise a coherent European ecological network of protected areas. Member States are required to take necessary measures to prevent the deterioration of natural habitats and the habitats of protected species. They are also required to take measures to prevent the disturbance of such species. Moreover, any project not directly connected with, or necessary to the management of, a Natura 2000 site but which is likely to have a significant effect upon it, either individually or in combination with other plans or projects, must be subject to an appropriate assessment of its likely impacts on the site in view of the Natura 2000 site's conservation objectives .

By way of example, in terms of siting decisions, in Greece the SFSPSDA prohibits the location of marine aquaculture farms on seabeds with marine vegetation (*Posidonia oceanica*, *Cymodocea nodosa*, *Zostera marina* and *Zostera moltii*) in accordance with the specific conditions and restrictions laid down by EU and national legislation governing these ecosystems including *Posidonia oceanica* grasslands located within protected areas of the Natura 2000 network. Moreover, farms that have been legally established to date in areas above identified *Posidonia* meadows or other protected habitats for which there is a need for protection cannot be given approval to increase production capacity. In addition, such a farm's establishment and operation licence cannot be renewed after its expiration and the farm is required to relocate.

5.3.2 Negative impacts from inputs

The next range of potential negative impacts from aquaculture, primarily environmental impacts but also social impacts, derive from inputs into aquaculture facilities. These impacts are addressed in a range of instruments adopted at EU level, many of which are in turn underpinned by the Official Controls Regulation[20]. The Official Controls Regulation sets out an overall framework for ensuring compliance with the application of food and feed law, rules on animal health and welfare, plant health and plant protection products.

5.3.2.1 Aquatic animals/plants

The introduction of aquatic animals/plants into aquaculture facilities can have negative environmental and social impacts, including negative impacts on the health of aquatic animals/plants already in those facilities and on wild stocks (including as a result of the spread of disease, the introductions of non-native species in the environment through escapes), pressure on source stocks (e.g., CITES listed and protected species). Further, the transportation of animals to a facility may have animal health and welfare

[18] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (*OJ L 20, 26.1.2010, p. 7*).

[19] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (*OJ L 206, 22.7.1992, p. 7*).

[20] Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products, amending Regulations (EC) No 999/2001, (EC) No 396/2005, (EC) No 1069/2009, (EC) No 1107/2009, (EU) No 1151/2012, (EU) No 652/2014, (EU) 2016/429 and (EU) 2016/2031 of the European Parliament and of the Council, Council Regulations (EC) No 1/2005 and (EC) No 1099/2009 and Council Directives 98/58/EC, 1999/74/EC, 2007/43/EC, 2008/119/EC and 2008/120/EC, and repealing Regulations (EC) No 854/2004 and (EC) No 882/2004 of the European Parliament and of the Council, Council Directives 89/608/EEC, 89/662/EEC, 90/425/EEC, 91/496/EEC, 96/23/EC, 96/93/EC and 97/78/EC and Council Decision 92/438/EEC (Official Controls Regulation)(OJ L 95, 7.4.2017, p. 1).

implications and the safe disposal of water used during transport is necessary to prevent the escape of pathogens in the water from the aquatic animals or plants being transported. These issues are addressed in a range of EU instruments.

For example, the Animal Health Law[21] sets out a complex legal framework for the prevention and control of animal diseases transmissible to animals or to humans. In terms of its scope, it also applies to 'aquatic animals' and contains specific definitions of 'aquaculture and 'aquaculture animals' (article 4). Title II, 'Aquatic Animals and Products of Animal Origin from Aquatic Animals', contains detailed provisions on aquaculture including in relation to the registration of aquaculture 'establishments', the approval of certain types of aquaculture establishment, record keeping, the movement of aquatic animals and measures to be taken regarding the detection and control of animal diseases. In terms of the health of aquatic plants used in aquaculture, the Plant Health Law[22], sets out rules to determine the phytosanitary risks posed by plant 'pests' and measures to reduce those risks to an acceptable level. The Alien and Locally Absent Species in Aquaculture Regulation[23], as its name implies, controls the use of alien and locally absent species in aquaculture, while the scope of the Invasive Species Regulation[24] is broader in that it seeks to prevent the introduction in general of invasive alien species that may threaten native plants and animals. The Protection of Farmed Animals Directive[25] also applies to fish but not to invertebrates, while the CITES Regulation[26] gives effect to the EU's Obligations under the Convention on International Trade in Endangered Species of Wild Flora and Fauna, 1973.

5.3.2.2 Feed

The feed used in the cultivation of aquatic animals in aquaculture can have a range of potential negative impacts. These include negative impacts on fish health due to the use of poor-quality feeds and negative impacts on human health from food produced from aquaculture as a result of the use of poor-quality feeds and residues from medicated feeds. In addition, the use of wild fish for feed that may have a food use, are an endangered species or are sourced from unmanaged fisheries may have negative environmental impacts (although in the context of feed produced in the EU, the Basic Regulation on the CFP should prevent the use of fish from unmanaged sources).

Again, these issues are systematically addressed at EU level through: the General Food Law[27], which sets out general principles and requirements of food law in the EU; the Feed Regulation[28], which sets out requirements for the marketing, labelling and composition of animal feed and includes provisions intended to safeguard both animal

[21] Regulation (EU) 2016/429 of the European Parliament and of the Council of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health ('Animal Health Law') (Text with EEA relevance) (OJ L 84, 31.3.2016, p. 1).

[22] Regulation (EU) 2016/2031 of the European Parliament of the Council of 26 October 2016 on protective measures against pests of plants, amending Regulations (EU) No 228/2013, (EU) No 652/2014 and (EU) No 1143/2014 of the European Parliament and of the Council and repealing Council Directives 69/464/EEC, 74/647/EEC, 93/85/EEC, 98/57/EC, 2000/29/EC, 2006/91/EC and 2007/33/EC (OJ L 317, 23.11.2016, p. 4)(Plant Health Law).

[23] Council Regulation (EC) No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture (OJ L 168, 28.6.2007, p. 1).

[24] Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species (OJ L 317, 4.11.2014, p. 35).

[25] Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes (OJ L 221, 8.8.1998, p. 23).

[26] Council Regulation (EC) No 338/97 of 9 December 1996 on the protection of species of wild fauna and flora by regulating trade therein (OJ L 61, 3.3.1997, p. 1).

[27] Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (OJ L 31, 1.2.2002, p.1)(General Food Regulation).

[28] Regulation (EC) No 767/2009 of the European Parliament and of the Council of 13 July 2009 on the placing on the market and use of feed, amending European Parliament and Council Regulation (EC) No 1831/2003 and repealing Council Directive 79/373/EEC, Commission Directive 80/511/EEC, Council Directives 82/471/EEC, 83/228/EEC, 93/74/EEC, 93/113/EC and 96/25/EC and Commission Decision 2004/217/EC (OJ L 229, 1.9.2009, p.1).

and human health; the Additives Regulation[29], which sets out rules on the authorisation of the use of additives in animal feed, feed additive authorisations, conditions on the use of additives and provisions labelling; the Feed Hygiene Regulation[30], which sets out rules on feed hygiene, mechanisms to ensure traceability of feed and conditions and arrangements for registration and approval of feed businesses; the Medicated Feed Regulation[31], which among other matters prohibits the use of antimicrobials in medicated feed for prophylaxis and growth promotion, requires the use of medicated feed to take place on the basis of veterinary prescriptions, and sets out harmonised limits for antimicrobials in ordinary feed and EU harmonised standards for the safe manufacturing of medicated feed; and the Residue Limits Regulation[32], which sets out maximum residue limits for pharmacologically active substances in foodstuffs of animal origin.

5.3.2.3 Medicines

The incorrect or excessive use of medicines or the use of unauthorised or unsafe medicines can contribute to the growing problem of anti-microbial resistance (AMR). These issues are addressed at EU level in: the Veterinary Medicinal Products Regulation[33], which regulates the manufacture, authorisation, marketing, distribution and post-authorisation surveillance of veterinary medicines; the Medicated Feed Regulation[34]; and the Residue Limits Regulation[35]. In Ireland all aquaculture of Atlantic salmon is certified as organic, in accordance with Organic Production Regulation[36], which imposes restrictions on the frequency of therapeutic medication and pesticide use (Bord Iascaigh Mhara, 2018), likely helping to limit AMR and tolerance to other pharmeceuticals and pesticides.

5.3.2.4 Chemicals

Chemicals and chemical products, including biocides, anti-fouling agents and fertilisers, are used for a range of purposes in aquaculture, including removal of weed, cleaning and treatment. The use or misuse of such chemicals/chemical products can have negative impacts on the environment (in terms of water quality and biodiversity) and ultimately on aquatic animals and plants, with possible human health impacts from residues in the case of aquaculture products used for food. Chemicals are addressed in a large body of EU legislation[37]. Of relevance to the mitigation of negative impacts from their use in aquaculture are: the REACH Regulation[38], which sets out the basic framework for the registration, evaluation, authorisation and restriction of chemicals in

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[29] Regulation (EC) No 1831/2003 of the European Parliament and of the Council of 22 September 2003 on additives for use in animal nutrition (OJ L 268, 18.10.2003, p. 29).

[30] Regulation (EC) No 183/2005 of the European Parliament and of the Council of 12 January 2005 laying down requirements for feed hygiene (OJ L 35, 8.2.2005, p. 1).

[31] Regulation (EU) 2019/4 of the European Parliament and of the Council of 11 December 2018 on the manufacture, placing on the market and use of medicated feed, amending Regulation (EC) No 183/2005 of the European Parliament and of the Council and repealing Council Directive 90/167/EEC (OJ L 4, 7.1.2019, p. 1).

[32] Commission Regulation (EU) No 37/2010 of 22 December 2009 on pharmacologically active substances and their classification regarding maximum residue limits in foodstuffs of animal origin (OJ L 15, 20.1.2010, p. 1).

[33] Regulation (EU) 2019/6 of the European Parliament and of the Council of 11 December 2018 on veterinary medicinal products and repealing Directive 2001/82/EC (OJ L 4, 7.1.2019, p. 43).

[34] Regulation (EU) 2019/4 of the European Parliament and of the Council of 11 December 2018 on the manufacture, placing on the market and use of medicated feed, amending Regulation (EC) No 183/2005 of the European Parliament and of the Council and repealing Council Directive 90/167/EEC (OJ L 4, 7.1.2019, p. 1).

[35] Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC Text with EEA relevance. OJ L 70, 16.3.2005, p. 1

[36] Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007(OJ L 150 14.6.2018, p. 1).

[37] See: the EU Chemicals Legislation Finder at https://echa.europa.eu/legislation-finder

[38] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (OJ L 396, 30.12.2006, p. 1).

the EU; the Plant Protection Products Regulation[39], which regulates the placing on the market of plant protection products; the Labelling Regulation[40], which regulates the classification, labelling and packaging of chemical substances and mixtures; the Approved Active Substances Regulation[41],which sets out the active substances that can be used in plant-protection products that are placed on the market; and the Evaluation of Plant Protection Products Regulation[42], which sets out the principles and procedures for evaluating plant products and authorising their placing on the market.

5.3.3 Negative impacts from the operation of aquaculture facilities

Negative social and environmental impacts can also arise from the operation of aquaculture facilities.

5.3.3.1 Social impacts

Negative social impacts from aquaculture may arise from the poor employment terms of workers in aquaculture facilities and health and safety aspects of work in and around water. At EU level this does not appear to be a particular issue as the rights of EU workers are framed with a developed framework of EU employment law, including the Working Time Directive[43], which will not be further described here. Because work in aquaculture involves activities in, on or adjacent to water, it invariably involves risks to workers. The overall framework for worker safety at EU level, including aquaculture workers, is set out in the OSH Framework Directive, which imposes a basic duty upon employers to ensure the safety and health of workers in every aspect related to the work (article 5)[44].

No specific legislation on aquaculture workers has been identified at either EU or Member State level.

5.3.3.2 Environmental impacts

The operation of aquaculture facilities may have a range of negative environmental impacts. These include negative impacts on water quality (due to the discharge of waste from aquaculture facilities in general and un-consumed feed from cages, nets and pens and the discharge of effluent and sludge from aquaculture ponds), potential reductions in wild stock fitness (as a result of interbreeding and disease transmission due to escapes from aquaculture facilities), negative impacts on protected species in the context of predator control measures as well as negative impacts from lost equipment, including nets (which contribute to the high levels of plastic in the marine environment).

Some of these negative impacts are addressed in and/or mitigated by control over the inputs used in aquaculture, as described above. Otherwise, negative impacts from aquaculture operations in freshwater/brackish water and coastal waters (which extend one nautical mile from the baseline from which the breadth of the territorial sea is

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[39] Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC (OJ L 309, 24.11.2009, p. 1).

[40] Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (OJ L 353, 31.12.2008, p. 1).

[41] Commission Implementing Regulation (EU) No 540/2011 of 25 May 2011 implementing Regulation (EC) No 1107/2009 of the European Parliament and of the Council as regards the list of approved active substances (OJ L 153 11.6.2011, p. 1).

[42] Commission Regulation (EU) No 546/2011 of 10 June 2011 implementing Regulation (EC) No 1107/2009 of the European Parliament and of the Council as regards uniform principles for evaluation and authorisation of plant protection products Text with EEA relevance (OJ L 155, 11.6.2011, p. 127).

[43] Directive 2003/88/EC of the European Parliament and of the Council of 4 November 2003 concerning certain aspects of the organisation of working time (*OJ L 299, 18.11.2003, p. 9*).

[44] Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (OJ L 183, 29.6.1989, p. 1) (OSH Framework Directive).

measured) are addressed at EU level through: the Water Framework Directive (WFD)[45] and the Environmental Quality Standards & Priority Substances Directive[46] (EQS Directive). The WFD creates a framework for water protection and sets out as a basic obligation the achievement of 'good surface water status'. This in turn depends on the achievement of (a) good 'ecological status' and (b) good 'chemical status' by reference to compliance with environmental quality standards established by the WFD and other EU legislation, including the EQS Directive. The Marine Strategy Framework Directive (MSFD)[47], which constitutes the environmental pillar of the EU's Integrated Maritime Policy, applies to all 'marine waters': the waters, seabed and subsoil that extend from the baseline of the territorial sea to the 'outermost reach of the area where a Member State has or exercises jurisdiction'. The MSFD requires that Member States 'take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 at the latest' (art. 1(1)).

As mentioned above, the Birds Directive and Habitats Directive also require that Member States protect particular species that may interact with aquaculture facilities, while the disposal of solid wastes from aquaculture is regulated in accordance with the Waste Framework Directive[48]. Health rules relating to animal by-products, which include by-products from aquatic animals, are set out in the Animal By-products Regulation[49]. Finally, the Single-use Plastics Directive[50] seeks to reduce the impact of plastic products in the environment via the introduction of extended producer responsibility schemes that apply to fishing gear that contains plastic. The term 'fishing gear' is defined in article 3 to include equipment used for aquaculture that floats on the sea surface and that is used to rear marine biological resources.

At the Member State level, these obligations are implemented in a range of ways. For example, in Greece, aquaculture licensing is subject to mandatory environmental licensing, which is carried out in accordance with Law 4014/2011 'Environmental licensing of projects and activities, regulation environmental balance and other provisions of competence of the Ministry of Environment' (Government Gazette A/209/21-09-2011). Such licences reflect the obligations of Law 3937/2011 'Conservation of biodiversity and other provisions' (Government Gazette A/60), which in turn gives effect to a number of EU Directives concerned with the environment, including the Water Framework Directive, the Birds Directive and the Habitats Directive.

In Germany, it is necessary to obtain multiple permits in accordance with a range of laws, including water, building and environmental protection legislation, before a permit authorising the construction of a trout flow-through farm can be authorised. In addition, specific authorities in local municipalities can require that farms show expert reports on the expected effects on the environment. Permits to use freshwater resources in the form of water rights are only given for a limited number of years, after which the farms have to apply for an extension. Significant changes in production also require that farms reapply for permissions. These obligations and limits in the permits ensure that water

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[45] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (OJ L 327, 22.12.2000, p. 1). As regards the chemical status of surface water the directive and the environmental objectives that must be achieved, the directive also applies to the territorial waters of each Member State.

[46] Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council (OJ L 348, 24.12.2008, p. 84).

[47] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (OJ L 164, 25.6.2008, p. 19).

[48] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3).

[49] Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (OJ L 300, 14.11.2009, p. 1

[50] Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment (OJ L 155, 12.6.2019, p. 1–19).

quality of the outflowing water does not negatively affect the natural ecosystems or that minimum water flow rates in the rivers are kept.

The other main approach is through the aquaculture licence itself. In Ireland, for example, measures to prevent damage to the benthic environment from organic matter sedimentation form part of the licensing requirements for Atlantic salmon aquaculture. Licence conditions require that farmers minimise waste production, conduct annual independent monitoring under the Offshore Finfish Farms – Benthic Monitoring Protocol, and conduct appropriate fallowing of the site according to the Offshore Finfish farms – Fallowing Protocol. Similarly, licence conditions require that aquaculture operations must be carried out in compliance with the international guidelines on containment of farm salmon (CNL(01)53), developed by the North Atlantic Salmon Conservation Organisation (NASCO) and the International Salmon Farmers Association (ISFA), and licensed facilities must also comply with the Protocol for Structural Design of Marine Finfish Farms. The legislation goes on to provide that in the event of escapes, the licence holder must notify the relevant authorities within 24 hours, keep a record of the number of fish that escaped, and attempt to recapture fish where practicable.

Deterring predators can be a problem for aquaculture farmers, particularly where such predators are themselves protected species. For example, in Germany, cormorants (*Phalacrocorax carbo, L.*) are strongly protected under the Federal Nature Conservation Act (BNatSchtG), which prohibits pursuing, catching, injuring or killing them. However, the nature conservation authorities of the federal states may allow exceptions in order to prevent considerable damage to fisheries, wildlife or economics and to protect naturally occurring fauna and flora if reasonable alternatives are not available. Based on this legal framework, most of the states allow killing cormorants under local and mostly temporal restrictions. On the other hand, there are no exceptions to the strict protection for fish otters (*Lutra lutra*). In some of the federal states, fish farmers can apply for financial compensation to cover wildlife damage. Financial support also exists for protective measures against predators, including spans, enclosures and fences.

5.3.3.3 Negative impacts on animal health and plant health

Negative social impacts from aquaculture operation may arise from animal health impacts, including the spread of aquatic animal and plant health diseases, as well as concern over the welfare of farmed animals. While health issues are addressed in the Animal Health Law and the Plant Health Law, farmed fish have limited welfare protection under EU and national legislation. While the Protection of Farm Animals Directive[51] sets out minimum standards for the protection of all farmed animals, specific provisions for aquaculture species are lacking. Moreover, the directive does not apply to invertebrate animals. Consequently, in Ireland the legislation that transposes the directive, the Animal Health & Welfare Act 2013, makes no mention of aquaculture other than in the regulations apply to farmed animals. Animal welfare concerns are not limited to salmon aquaculture in Ireland: welfare is a major topic of debate across the global aquaculture sector (Ashley, 2007; Franks et al., 2021).

At present, animal welfare is under-regulated at EU and national levels. Existing regulation does not adequately reflect the specific challenges faced in the aquaculture sector, nor do regulations contain the appropriate specificity required to address welfare concerns across different aquaculture species and methods. Improving welfare regulations at EU and national levels would appear to be a clear priority.

[51] Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes (OJ L 221, 8.8.1998, p. 23.)

5.3.4 Post-production impacts from aquaculture

5.3.4.1 Food safety and traceability

Negative social impacts relating to food safety include the impacts of chemical and other residues in food products from aquaculture and the risk of zoonosis (the spread of disease to humans). Traceability in the aquaculture sector aims to ensure both the safety and quality of aquaculture products and aims to verify that they have been farmed in compliance with applicable standards. At EU level, safety and traceability of food products from aquaculture is addressed in the Control Regulation[52] which sets out a mandatory system for the traceability for fish products in general. Food safety issues are also addressed at EU level in the Food Regulation, the Food Hygiene Regulation[53] and the Residues Regulation[54].

5.3.4.2 Animal health and welfare

The way aquatic animals are transported or harvested may have negative social impacts because of concerns over animal welfare. The issue of animal welfare is addressed at EU level by the Animal Health Law[55] as well as by the Protection of Farmed Animals Directive, the Animal Transport Regulation[56] and the Animal Killing Regulation[57].

In Germany the welfare of farmed trout is covered in multiple German laws. The Animal Welfare Act (*TierSchG*), the Animal Protection Slaughter Ordinance (*TierSchlV*), the Fish Disease Ordinance (*FischSeuV*), and the Animal Protection Transport Ordinance (*TierSchTrV*) are of central relevance here. For example, the animal welfare act requires aquaculture production to sedate fish before killing or surgery and strictly defines stunning methods.

5.4 The scope of the regulatory framework for aquaculture

As is clear from the previous section, the regulatory framework for aquaculture at EU and Member State level is extensive. Moreover, it appears to be rather complete in that it addresses the impacts identified by the FAO (FAO 2011) (Table 11) and indeed goes further in that it also addresses the negative impacts that may arise from the siting of aquaculture facilities. In other words, the regulatory framework for aquaculture in the EU accords with international standards for the control of responsible aquaculture.

At the same time, 'European citizens are often unaware of the extensive regulatory framework in place' as described above and in the case studies. The EU legal framework and the FAO attribute significant social impacts to effects on labour rights, such as working hours and health and safety, both of which are significant features of working in aquaculture alongside the potential positive impacts on earning and employment. However, these social impacts do not feature prominently in the scientific literature. The

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[52] Council Regulation (EC) No 1224/2009 of 20 November 2009 establishing a Union control system for ensuring compliance with the rules of the common fisheries policy, amending Regulations (EC) No 847/96, (EC) No 2371/2002, (EC) No 811/2004, (EC) No 768/2005, (EC) No 2115/2005, (EC) No 2166/2005, (EC) No 388/2006, (EC) No 509/2007, (EC) No 676/2007, (EC) No 1098/2007, (EC) No 1300/2008, (EC) No 1342/2008 and repealing Regulations (EEC) No 2847/93, (EC) No 1627/94 and (EC) No 1966/2006 (OJ L 343, 22.12.2009, p. 1).

[53] Regulation (EC) No 852/2004 of the European Parliament and of the Council of 29 April 2004 on the hygiene of foodstuffs (OJ L 139, 30.4.2004, p. 1).

[54] Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC

[55] Regulation (EU) 2016/429 of the European Parliament and of the Council of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health ('Animal Health Law') (Text with EEA relevance) (OJ L 84, 31.3.2016, p. 1).

[56] Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97 (OJ L 3, 5.1.2005, p. 1).

[57] Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing (OJ L 303, 18.11.2009, p. 1).

main gap or omission, as described above, concerns the welfare of aquatic animals – given the absence of specific provisions on animals used in aquaculture in the relevant legislation and the fact that the legislation does not apply to invertebrates.

Table 11: Impacts affected by legal regulations at the EU level and those considered by the FAO to be most impactful from aquaculture

	Impact	Legal	FAO
Impacts from siting			
Land use	Unregulated siting/zoning non-compliance	✓	
	Loss of amenity value	✓	
	Loss of landscape value	✓	
Use of maritime space (near shore/offshore area)	Inappropriate siting/zoning compliance	✓	
	Conflict with other uses of the sea	✓	
	Protected areas/protected species/migratory routes	✓	
Navigation (riverine, near shore, offshore)	Non-obstruction of navigation routes	✓	
	Navigation hazards	✓	
Land degradation (coastal land/inland)	Abandoned/closed sites	✓	
Coastal zone	Aquaculture in ecologically sensitive/vulnerable areas	✓	
	Conflict with other uses of the coastal zone	✓	
	Destruction of lagoons, mangroves, reefs, natural storm surge/flooding systems	✓	
Environmental impacts	Siting in protected areas	✓	
	Negative impacts on protected species/biodiversity	✓	
	Interference with migration paths	✓	
	Siting in ecologically sensitive areas	✓	
	Habitat restoration		✓
Impacts from inputs			
Animal/plant	Impacts on animal/plant health	✓	✓
	Impacts on wild stocks (disease, introductions, biosafety)		
	Pressure on source stocks (e.g., CITES, protected species)	✓	✓
	Transport (e.g., animal health, transport water disposal)	✓	
Feed	Negative human/fish health impacts due to unsafe residue levels	✓	✓
	Medicated feed impacts (no prophylactic use of medications)	✓	✓
	Use of fish that may have a food use, endangered species, species from poorly managed fisheries	✓	
Medicines/ therapeutants	Accidental misuse/application due to marking, storage requirements or poor diagnosis	✓	✓
	Antibiotics/resistance	✓	✓
	Human health impacts (residues)	✓	✓
Chemicals	Environmental impacts (water quality, biodiversity)	✓	
	Human health impacts	✓	✓
	Animal/plant health impacts	✓	✓
	Accidental misuse/application due to marking, storage requirements	✓	

	Impact	Legal	FAO
Impacts from operation			
Social impacts	Employment rights of workers	✓	✓
	Health and safety	✓	✓
Environmental impacts	Pelagic discharge/ water quality (N/P)		✓
	Waste disposal: effluent	✓	✓
	Waste disposal: sludge, dead aquatic animals, plants	✓	
	Impact on wild stocks	✓	
	Escapes	✓	✓
	Transgenic practices (polyploidy excluded)	✓	✓
	Disease	✓	
	Waste disposal, effluent	✓	✓
	Waste disposal, sludge	✓	✓
	Predator control impacts on protected species	✓	✓
	ALDFG	✓	
Animal/plant health impacts	Disease	✓	
	Animal welfare	✓	✓
Impacts post-production			
Food safety & traceability	Residues	✓	
	Zoonosis	✓	
Animal health	Transport	✓	✓
	Harvesting/slaughter		✓

In terms of the scope of aquaculture legislation, one further issue that emerges in particular from the Greek legislation is the legal status of the cultivation of microalgae. The question that arose is whether or not this activity is properly categorised as aquaculture, and therefore subject to Greece's aquaculture legislation, or better understood as a separate industrial process. In the case of Greece, it was finally determined that microalgae should be regulated as an aquaculture activity, but it is possible that this issue may arise in other jurisdictions.

5.5 Attempting to assess whether or not the regulatory framework is effective in mitigating the negative impacts of aquaculture

After reviewing the regulatory framework for aquaculture, the terms of reference required the study look at whether the regulatory framework has had any effect on the negative impacts of aquaculture identified in order to determine whether some have proved effective in mitigating those impacts.

Assessing the effectiveness of a regulatory framework in terms of the extent to which it effectively mitigates negative impacts is challenging by any standard for any sector. For aquaculture, the complexity of the legal framework is a particular challenge, as outlined above, as is the fact that most of the legislation relevant to the aquaculture sector is not primarily concerned with or addressed to the aquaculture sector and often has a range of other social, economic and environmental objectives. Of the 50 or so legal instruments identified at the EU level, only one instrument (the Alien Species Regulation) actually has 'aquaculture' in its title. Regarding other instruments that make up the overall legal framework for aquaculture, some contain articles or even chapters on aquaculture (such as Article 15 of the Organic Production Regulation, which sets out specific production rules for algae and aquatic animals). Other instruments contain references to aquaculture while others are entirely silent on the topic even though they may well address directly or indirectly some of the negative impacts that may arise from the sector (such as chemicals or waste for example).

In designing the approach to the study, a number of assumptions were made. In addition, it should be recalled that the study was undertaken on the basis of a science framework contract by consortia made up essentially of scientific institutions rather than law firms. Moreover, the case studies include only a review of the legislation rather than in-depth analyses of the functioning of the legislation.

The first assumption was that Task 1, the review of scientific literature, would provide a clear picture of the negative impacts of aquaculture. The original idea was to use the case studies to confirm the findings of the literature review and to investigate trends in the mitigation of negative impacts in terms of the different types of technology used. In fact, it soon became clear that the scientific literature reviewed in Task 1 did not provide a clear picture of many of the well-known negative impacts from aquaculture – impacts that are addressed in the legislation. There are a number of reasons for this, including the fact that there is presumably little scientific interest in researching well-known impacts.

Consequently, the case studies, including the interviews with key experts, became the main information source. Moreover, the research undertaken during the course of this study revealed limited literature on aquaculture legislation let alone its effectiveness in addressing negative impacts. In addition, due to the instruction to rely on the science and to avoid the risk of opinion or perceptions about the sector, the interviews were restricted to a rather limited category of key experts as described in section 5.2 above. In other words, a broader stakeholder perspective is lacking.

Moreover, the mere existence of legislation on the statute books tells only part of the story. Larger and more complex questions arise in relation to the implementation and enforcement of that legislation, and the resources made available to that end. Most of the elements of the EU legal framework for aquaculture are in the form of regulations (Table 12) that are directly applicable.

Table 12: EU legislation concerning aquaculture

Regulations relevant to aquaculture	Directives relevant to aquaculture
Basic Regulation on the Common Fisheries Policy	MSP Directive
Official Controls Regulation	EIA Directive
Alien Species in Aquaculture Regulation	SEA Directive
Invasive Species Regulation	Birds Directive
CITES Regulation	Habitats Directive
General Food Regulation	Water Framework Directive
Feed Regulation	Marine Strategy Framework Directive
Additives Regulation	Protection of Farmed Animals Directive
Feed Hygiene Regulation	Working Time Directive
Medicated Feed Regulation	OSH Framework Directive
Residue Limits Regulation	EQS & Priority Substances Directive
Veterinary Medical Products Regulation	Single Use Plastics Directive
Medicated Feed Regulation	Waste Framework Directive
Organic Production Regulation	
REACH Regulation	
Plant Protection Products Regulation	
Labelling Regulation	
Approved Active Substances Regulation	
Evaluation of Plant Protection Products Regulation	
Animal By-products Regulation.	
Control Regulation	
Food Hygiene Regulation	
Animal Transport Regulation	
Animal Killing Regulation	

A more detailed set of findings regarding the effectiveness of the regulatory framework for aquaculture would require a much larger study involving public consultation with a much wider range of stakeholders, as well as the involvement of one or more national legal expert(s) for each relevant jurisdiction (because of the broad scope of the legal framework for aquaculture, it may be unlikely that a single legal expert would be familiar with all of its elements).

A number of further points arise here. First, the nature of the negative environmental impacts from aquaculture will clearly vary depending on the type of facility/technology used, as will the ability of both technological and regulatory responses to mitigate those impacts. Second, even for the same type of technology, the impacts and the ability of the regulatory framework to mitigate those impacts may well vary for a range of reasons, including the legal system of the jurisdiction concerned and the ecosystem in which aquaculture is undertaken. For example, the quality of water in the area immediately around a cage or pen, may depend as much on the existence and strength of the tides there as on the substance, implementation and enforcement of the relevant legislation. Third, the relative degree of experience with a particular technology may affect the findings. Put simply, in the case of aquaculture that makes use of new technology or techniques and where there is as yet little practical experience, there may be a greater awareness of potential impacts that have yet to materialise and indeed may never materialise. Fourth, some types of negative impact from aquaculture, such as conflict over land/maritime space, may not be susceptible to a purely regulatory response but instead depend on questions of social acceptability.

In this connection, while the findings of the key expert interviews in Figure 13 set out the relative importance of the negative impacts, it is, unfortunately, not possible to draw a direct causal link between the elements of the regulatory framework and the ability of that framework to mitigate negative impacts from aquaculture. Instead, the best that can be done is to undertake a preliminary analysis based on the results received that at most can identify issues for further research. This analysis is set out in the following paragraphs and confined to the results of the key expert interviews, backed up with the information in the case studies, for the technologies described in Figure 13 for: (a) sea cage and net pens; (b) PTRs; (c) RASs; (d) shellfish; and (e) macroalgae. The survey results for microalgae and IMTA are too limited to make inclusion reliable. Moreover, the survey results for RASs seem rather negative for a type of aquaculture that effectively functions in a closed system, almost as if all possible negative impacts are foreseen. Perhaps this is a result of the relative novelty of RASs.

5.5.1 Negative impacts from siting/land use

As noted above, the main negative social and environmental impacts from aquaculture tend to depend on the siting of aquaculture facilities. The study findings suggest that negative impacts as a result of impacts on existing/other land are an important issue for sea cages, for shellfish and macroalgae aquaculture. In addition, the loss of amenity value and loss of landscape value is identified as a negative impact from sea cage/net pen facilities but not for shellfish and macroalgae culture. One possible reason for this difference may be that shellfish and macroalgae facilities have fewer negative impacts on landscapes and little impact on amenity in contrast to the usually larger and more visibly intrusive sea cage facilities.

Aquaculture in Member States is subject to relatively complex regulatory frameworks for land use/development planning, set out in national legislation. Such frameworks by their nature seek to balance conflicting claims of space and seek to mitigate the most serious impacts through a spatial planning regime. To a very real extent, the problem, such as it is, may simply be one of increased competition for limited space.

No negative impacts on land use from ponds, tanks and raceways are identified either because the facilities themselves are long established or because the relevant land-use planning frameworks have mitigated such impacts.

Negative impacts on ecologically sensitive areas in the coastal zone as well as other uses of the coastal zone are also identified as a negative impact from aquaculture in respect of the siting of shellfish and macroalgae facilities. This is not an area that is subject to EU legislation; although, as already seen, some countries such as Spain have specific coastal-zone legislation in place[58]. Even here, though, legislation can never completely mitigate the negative impacts of competition for limited space.

Regarding negative impacts relating to the use of maritime space, conflicts with other uses emerge as an issue for sea cages facilities and as a serious impact for shellfish and macroalgae culture. In addition, effects on wild species and migratory routes also emerge as negative impacts from sea cages. This is an area for which the EU has recently established a regulatory framework with the adoption of the MSP Directive. However, the deadline for adopting maritime spatial plans was 12 March 2021, so it would be premature to argue that this instrument is not effective in terms of mitigating negative impacts. But again, as one of the French interviewees observed, the problem ultimately arises because available space is limited.

Negative impacts for navigation in terms of the obstruction of routes do not emerge as an issue for sea cages or for shellfish and macroalgae facilities: the case studies show that there are coordination systems in place with the navigation authorities. On the other hand, while cages and pens are large enough to be marked and lit to alert ships of possible hazard, the structures used for shellfish and macroalgae culture tend to be low lying or under water (at high tide) and therefore more difficult to mark or light. This may be why navigation hazard is identified as a negative impact for these types of aquaculture. Further research on this issue is necessary.

The issue of abandoned/closed sites emerges as a negative impact for sea cages but not for shellfish or macroalgae. This is not an issue that has been addressed in EU law and is instead usually addressed in the lease or concession that authorises the use of public land (including the seabed) for aquaculture or is addressed in the relevant aquaculture law, as in the case of article 22 of the Portuguese aquaculture law mentioned above.

Conversely, key expert interviews suggest that negative impacts from the siting of cage and pen facilities seems have been largely mitigated through, as described above, specific rules relating to *Posidonia* beds in Greek waters, and equivalent restrictions in Irish legislation. This is an area covered by extensive EU legislation, including the EIA Directive, the Birds Directive and the Habitats Directives.

For macroalgae, which is a relatively new type of aquaculture in Europe, it seems reasonable to assume that the negative environmental impacts are identified primarily in terms or risks or concerns rather than an actual failure of the regulatory framework to mitigate negative impacts.

For ponds, tanks and raceways, negative impacts from siting, and impacts from siting within protected and ecologically sensitive areas are the only negative impacts in Table 13. Again, this may simply be a result of the delicate nature of human interactions in such areas and it may also recognise the fact that in Germany, in many cases, carp ponds have become protected areas. Otherwise, ponds tanks and raceways are not identified as generating negative impacts from the siting of facilities. The overall low number of negative impacts may be because the regulatory framework is effective or because such facilities are-long established and their existence no longer causes conflict.

Unsurprisingly, given the self-contained nature of the technology used, Table 13 shows no negative impacts from siting for RASs apart from competition with other uses of land, which is probably as much as an indicator for overall demand for land as it is for anything else.

[58] Law 22/1988, of 28 July on the Coasts. BOE-A-1988-18762.

5.5.2 Negative impacts from inputs

Inputs in terms of aquatic animals, feed or medicines do not emerge as a negative impact for sea cages, suggesting that the regulatory framework may be effective for this type of technology. Otherwise, the only important negative impacts are negative environmental impacts from the use of chemical pesticides (in terms of water quality and biodiversity), suggesting that the regulatory framework is not fully effective in this respect. However, given the nature of sea cages and net pens, which are used in the sea, and the considerable body of EU regulation on inputs, this may be a result of poor implementation/enforcement as much as any weakness in terms of the regulatory framework itself.

Neither shellfish nor macroalgae culture depend on feed or medicines. Therefore, the fact that the key expert interviews for both types of aquaculture refer to negative impacts as a result of the input of diseased animals/plants and possible impacts on wild stocks as a result of such animals and plants is surprising and difficult to interpret. In addition, the risks of negative impacts from transport in terms of animal health/welfare and disposal of water used in transport (which may contain pathogens) also emerges as a negative impact for shellfish. In the case of macroalgae this may be because the overall legal framework for the sector is less developed at EU level; but this is not the case for shellfish, which have long been a key focus of animal health legislation.

The negative impacts from chemicals/pesticides identified for the macroalgae sector are considered in different contexts in the questionnaire. First, the macroalgae sector has very real concerns over residues in macroalgae products including from heavy metals. Second, the negative impact of land-based use of chemicals on macroalgae facilities was referred to in a number of the interviews, although those are clearly negative impacts on aquaculture rather than from aquaculture.

The negative findings in Table 13 regarding RASs are difficult to interpret because such systems do not discharge water or waste to the natural environment. Again, these negative findings for RASs probably relate to more general concerns about sustainability rather than a specific weakness concerning the regulatory framework that applies to RAS facilities.

5.5.3 Negative impacts from operations

In the case of the operation of aquaculture facilities, negative impacts on protected species as a result of predator control are identified as the only ongoing negative effect for ponds, tanks and raceways. As described in the relevant case studies, this is an issue that is fully regulated but is a negative impact that can probably never be fully mitigated even if the mortality level for protected predator species is kept as low as reasonably possible.

Impacts on water quality from the use of chemicals/pesticides, impacts on wild stocks due to escapes and disease, solid waste disposal, animal disease and animal welfare all emerge in Table 13 as negative impacts from the operation of cages. Most of these issues are addressed in EU legislation. However, it is unclear whether the perception of negative impacts means that the legislation is not effective or whether negative impacts are effectively mitigated but can never be mitigated fully (e.g., there is always some chance of escape even when mitigation is in place, because there is always a risk of cages being damaged by storms or other weather events). The challenge of managing chemical/pesticide use in an open environment has already been referred to, while preventing escapes is also a constant practical challenge. Animal disease remains a problem for aquaculture around the world. Indeed, biosecurity is one of the main economic threats to the sector globally. On the other hand, as seen above, animal welfare in finfish aquaculture is an emerging issue for the sector. Comments on this issue in terms of the transport and slaughter of finfish were also raised by some of the pond, tank and raceway interviewees.

Once again, the findings in Table 13 relating to the impacts from operation for RASs are difficult to interpret – although negative social impacts for workers regarding employment rights and health and safety are the same as those for workers in shellfish and macroalgae. One other negative impact that emerged from the RAS key expert interviews is the high energy use of RASs, an issue that is broadly addressed as for other sectors through the European Climate Law[59] which establishes a framework for the irreversible and gradual reduction of anthropogenic greenhouse gas emissions and a binding objective of climate neutrality in the EU by 2050.

Waste disposal emerges as an issue for macroalgae, while animal disease in operations is, unsurprisingly, an issue for shellfish. Impacts from abandoned, lost or otherwise discarded gear (ALDFG) are cited in Table 13 for both shellfish and macroalgae; however, the recently adopted Single Use Plastic Directive should at least begin to address the issue of plastic waste from aquaculture.

5.5.4 Negative post-production impacts

For post-production, including post-harvest stage, residues and zoonosis are set out in Table 13 as negative impacts for cage aquaculture. Perhaps this is a matter of sensitivity in this present COVID era as the safety of seafood products is subject to a complex legal framework at EU level. Residues are also cited as a negative impact for macroalgae, which is a food safety impact rather than an environmental one.

[59] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')(OJ L 243, 9.7.2021, p. 1).

6 CONCLUSIONS

The aim of this study was to **establish a scientific basis for the positive and negative impacts** of European aquaculture from economic, environmental and social perspectives, in order to facilitate a well-informed debate. The study is therefore based on scientific evidence alongside expert opinions and not on public opinions.

The impacts of aquaculture are increasingly evaluated using holistic and interdisciplinary methodologies. This study performs an **analysis and evaluation of impact** rather than an impact assessment. The study has focused on cross-sectoral, taxonomic-specific, and technology-specific impacts, but does not seek to compare the scale of the impacts directly amongst sectors or alternative food production systems. Impacts of aquaculture are generally studied as isolated parts of the food-production system or ecosystem, where production-chain components and associated impacts are considered separately. The total contribution, cumulative impacts, and overall performance of the aquaculture sector as a component of the European food system should be considered in future programmes, and should cover single sectors or industry and integrate the impacts from a holistic perspective (Food system approach and planetary boundary principles).

Aquaculture **impacts** identified from the scientific literature were predominantly **environmental in nature** with limited focus on social and economic impacts. This is likely a result of the search parameters used in the scientific literature review, the interests of the academic sector, and the interests of research-funding institutions. The impacts of **finfish aquaculture have received the greatest attention** in the scientific literature (56.0 %), followed by shellfish (30.2 %), with algae (both macroalgae and microalgae) receiving the least (13.8 %). Algal culture at commercial scale is relatively new in the EU and, in the case of microalgae, often restricted to laboratory or pilot environments. The **scientific literature rarely addressed the social or economic impacts** from aquaculture in the EU, **nor the regulatory measures** surrounding the sector. The use of aquaculture case-studies within this project, alongside data from the STECF database has facilitated a better understanding of the social and economic impacts of aquaculture as well as the applicable regulatory framework.

The finfish-associated scientific literature is dominated by negative impacts (70.6 %), the shellfish scientific literature is balanced between positive (56.0 %) and negative impacts (44.0 %), and the algal (microalgae and macroalgae) scientific literature mostly positive (87.5 %). **Consensus on the major positive and negative impacts was relatively common** among scientific literature, the STECF database and the key expert consultation. Where consensus was found, confidence in the importance of these impacts is high. However, **disagreement on the positive and negative impacts of aquaculture was also common** and may serve to highlight impacts in need of further scientific focus to establish their level of importance. Disagreement may reflect the differing priorities of the research and regulatory communities, with the scientific community concerned primarily with assessing the potential of current and future risks, whereas the regulatory community is focused on controlling or mitigating realised risks. Both perspectives are vital in assessing the current impacts of aquaculture and warding against and/or preparing for future potential impacts.

Some social and economic impacts were seen consistently across aquaculture technologies and taxonomic groups. **Positive impacts** were most commonly the **current or potential levels of employment and income** derived from the sector, which often plays an important role in supporting rural communities and cultures, and low-skilled workers. Aquaculture provides greater **access to seafood** with associated benefits to **food security**, food quality and health and nutrition. **Aquaculture** has likely contributed to the stabilisation and possibly a **reduction of pressure on wild stocks**. However, as production from capture fisheries declines, the production from EU aquaculture has not risen to make up the shortfall, leaving the EU increasingly dependent on imports of aquaculture products. Both shellfish and algal *in situ* culture may also have benefits for water quality and protections against eutrophication and harmful algal blooms, but evidence for this at ecosystem scales under current production intensity is limited.

Negative impacts from aquaculture often included **conflict with other users** of the surrounding or adjacent land and the marine environment. As might be expected, environmental impacts were more variable across technology and taxonomic groups. However, there is **broad concern** in both the scientific literature and from the regulatory sector around the potential for *in situ* aquaculture of all taxonomic groups to result in **the introduction of non-native species**, weakening wild stock fitness as a result of genetic introgression, to act as vectors for disease and parasite transfer to wild stocks, and to result in the release of chemicals and pesticides into the wider environment. Similarly, the *in-situ* culture of both finfish and shellfish produce substantial volumes of **effluent discharge** (solid and dissolved), which may impact the wider environment; however, at current production levels, these impacts appear highly localised and thus unlikely to have wide-ranging impacts at the ecosystems scale. There is also growing concern, particularly from key experts, around the **welfare of finfish** in aquaculture. The growth and continued **development of *ex-situ*[60] systems** (RAS, laboratory grown, and to an extent ponds, tanks and raceways) and/or integrated multitrophic aquaculture are, welfare aside, positioned to **offset many of these negative impacts**. Further, evidence from national regulators indicate that the negative impacts of aquaculture are, despite public opinion to the contrary, seemingly well mitigated by existing monitoring and treatment programmes.

There is a **complex regulatory framework** for the aquaculture sector in the EU. The framework is comprised of instruments, adopted at the EU level and implemented by Member States, that seek to mitigate the negative impacts from aquaculture. European citizens are often unaware of the extensive regulatory framework in place for aquaculture. This work demonstrates that such a **framework is in place** and seeks to regulate the all relevant impacts, as identified in this study and by bodies such as the FAO. The case studies and questionnaires suggest that in general terms the regulatory **framework is likely somewhat effective in mitigating many of the negative environmental and social impacts** of aquaculture in the EU in part, if not entirely in some cases. The realities of aquaculture operations mean it is unrealistic to envisage the complete elimination of all negative impacts regardless of whether they are *in situ* or *ex situ*. However, there are areas emerging in which there is room to strengthen or further develop the regulatory framework. Specific **concerns remain around the regulation of impacts on animal welfare** (beyond the controls of stocking density and disease/parasites) and of the **framework surrounding the aquaculture of macroalgae and microalgae**.

Aquaculture is an established practice in Europe. While **there remain concerns within the scientific and regulatory communities around negative impacts** across production systems, **the positive impacts derived from aquaculture must be acknowledged**. If the aquaculture sector is able to achieve new growth, vigilance must be maintained via continued research, monitoring, technological innovation, and mitigation to counteract emerging or existing negative impacts, supported by a regulatory framework that **encourages the development of lower-impact production processes** for fin fish, bivalves and algae. In parallel, given the **public perception of aquaculture does not always align with the evidence**, open and transparent communication around aquaculture should be considered a priority to **dispel 'myths' while being upfront about the pitfalls**. A variety of positive impacts currently being studied in the context of ecosystem services need further development

[60] *Ex situ*, opposite of *in situ*, in this context it is aquaculture not carried out in the natural environment.

and contextualisation to enable enhancement and facilitation of benefits and social perception.

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The Annexes mentioned exist and can be obtained upon request to CINEA D3 (cinea-emfaf-contracts@ec.europa.eu).

ANNEX 1: DETAILED METHODOLOGY

ANNEX 2: SUMMARY OF DESK RESEARCH

ANNEX 3: CASE STUDY REPORTS

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