Credit for the pictures: ROMFISH (left) – Mexillón de Galicia (right)

The provision of ecosystem services by European aquaculture

June 2021 - (AAC 2021-08)

The Aquaculture Advisory Council (AAC) gratefully acknowledges EU funding support.

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1. Background and explanatory memorandum

Through the Commission communication "The European Green Deal", Europe reaffirms its commitment to respond to the climate and environmental challenges that will shape our common future.

Global warming and climate change on the one hand and the loss of biodiversity on the other are challenges that we must respond to if we want to guarantee a sustainable future[1].

In line with the Green Deal, the Commission has published a new Biodiversity Strategy for 2030, COM (2020) 380, which proposes actions and commitments to address the loss of biodiversity in Europe, and the Farm to Fork Strategy, COM (2020) 381, with which to facilitate the transition to a sustainable and equitable food system. Both strategies are interconnected by the conviction that a sustainable food system must preserve biodiversity.

In this context, European aquaculture must also contribute significantly to the protection of biodiversity, enhancing ecosystem services, preserving habitats and landscapes and constituting an important part of the EU's sustainable food systems, which can and should be diverse.

The objective of this document is to promote, protect and value biodiversity and ecosystem services by recognizing and supporting the European aquaculture that provides these services.

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[1] Rockström et al. (2009) and Steffeen et al. (2011, 2015) warn that the planet has exceeded its safe limits for certain biophysical processes, climate change and the rate of loss of biodiversity; these authors add the imbalance in the biogeochemical flow (mainly in the nitrogen and phosphorus cycle).

The other areas for which planetary boundaries have been defined are stratospheric ozone depletion, ocean acidification, global freshwater consumption, land use changes, atmospheric aerosol load, and chemical pollution (renamed 'new entities'). Although uncertainties remain in the evaluation of these last two limits, there is a strong consensus that all these problems are deeply interconnected, so there are no individualized solutions. In any case, the sustainable development of the world is only possible if the safety thresholds of these nine planetary processes are not exceeded.

Rockström, J., W. Steffen, K. Noone, Å. Persson, F.S. Chapin III, E.F. Lambin, T.M. Lenton, M. Scheffer, C. Folke, H.J. Schellnhuber, B. Nykvist, C.A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P.K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R.W. Corell, V.J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, J.A. Foley. (2009). A safe operating space for humanity. *Nature* 461, 472–475. https://doi.org/10.1038/461472a.

Steffen, W., J. Rockström and R. Costanza. (2011). How defining planetary boundaries can transform our approach to growth. *Solutions* 2 (3), 59–65.

Steffen, W., K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, R. Biggs, S.R. Carpenter, W. de Vries, C.A de Wit, C. Folke, D. Gerten, J. Heinke, G.M. Mace, L.M. Persson, V. Ramanathan, B. Reyers and S. Sörlin. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science* 347 (6223). https://doi.org/10.1126/science.1259855.

This will also contribute to the right to food of European citizens, which the UN defines as 'the right to have […] access, either directly or by means of financial purchases, to quantitatively and qualitatively adequate and sufficient food corresponding to the cultural traditions of the people to which the consumer belongs, and which ensures a physical and mental, individual and collective, fulfilling and dignified life free from anxiety'[2]. In the context of the COVID-19 pandemic this became not only more relevant but also of utmost importance.

2. Characterization of the aquaculture activities considered by this document

Just as on land, where there are many farms and many forms of livestock farming, in the aquatic environment there are also many aquacultures and a variety of practices with differentiating characteristics.

The EC Guidance document on aquaculture activities in the context of the Natura 2000 Network[3] describes three basic types of aquaculture:

(a) *extensive aquaculture*; there is no external supply of feed, and this type of culture depends entirely on natural processes for production and supply of feed;

(b) *semi-intensive aquaculture*; some supplementary feed may be used in addition to natural capacity to increase the production of fish;

(c) *intensive culture systems*; there is a greater dependency on the use of external feeds.

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[2] NNUU. (2002). Economic and Social Council Report of the Special Rapporteur of the Commission on Human Rights on the Right to Food. Fifty-seventh session. Item 111 (b) of the provisional agenda. A57/156.

[3]European Commission–DG Environment (2018). Guidance document on aquaculture activities in the Natura 2000 Network. Other possible definitions for these types of aquaculture can be found at http://www.fao.org/3/ad002e/AD002E01.htm, where aquaculture systems are classified on the basis of feed and fertilizer input:

- *Extensive systems* rely on natural feed produced without intentional inputs in the form of feed or fertilizers;
- *Semi-intensive systems* depend on fertilization to produce natural feed in situ in the pond and/or on feed given to the fish to complement the natural feed which develops in the pond;
- *Intensive systems* depend on nutritionally complete feeds, either in moist formulations or in dried pellet form, with fish deriving little or no nutrition from natural feed production in the pond.

Edwards, P. (1990). Environmental issues in integrated agriculture-aquaculture and wastewater-fed fish culture systems. Conference on Environment and Third World Aquaculture Development, Rockefeller Foundation, Bellagio, Italy, 17–22 September 1990.

An ecological approach definition can also be formulated that is linked to natural nutrient cycling. Based on it, two main types of aquaculture can be distinguished:

(a) *extensive aquaculture*; production is based on the nutrient cycle typical of natural ecosystems. These operate as open ecological systems, where natural and technological processes build on each other inseparably. Managerial interventions only enhance the natural processes to increase the productivity of target species;

(b) *Intensive aquaculture:* Production does not depend on the natural nutrient cycle; both input and output processes are decisively controlled by managerial interventions.

However, using any of these definitions for finfish aquaculture highlights that none of them reflects environmental sustainability. It should be emphasized that by applying good production practices and appropriate siting, both extensive (including semi-intensive) and intensive finfish aquaculture can meet the requirements of sustainability. So, this document does not assess aquaculture in terms of sustainability.

Aquaculture also includes aquatic plants and algae, which are an essential part of biocenosis and play important roles of providing oxygen, food and shelter, extracting nutrients, regulating CO_2 and stabilizing the sediments in freshwater, brackish water or seawater. Aquatic plants and algae provide ecosystem services both when farmed as target products or when included in different integrated multitrophic aquaculture systems, as they provide, among other benefits, a bioremediation service for effluents including intensive-extensive systems and RAS among others.

Some of the ecosystem services generated by algae are detailed in the Aquaculture Advisory Council (AAC) seaweed recommendation[4]; while some are cited in this document as linked to various types of aquaculture, at this stage, this document refers only to

- bivalve mollusc cultures and
- extensive and semi-intensive fish farming carried out in lagoons, estuaries, ponds and reservoirs.

As these aquaculture activities require low inputs, it is acknowledged that their negative impacts on the environment and environmental footprints are relatively small and reversible. This does not mean, however, that they have no impact that should be corrected or minimized. For example, the widespread use of plastics and their mismanagement in modern societies is a general evil found in all activities. However, these issues are not the specific subject of this document.

[4] In final approval process in the ExCom.

Extensive and semi-intensive fish farming and bivalve mollusc cultures have a very long tradition of more than two millennia in Europe and have established an important role in society.

The two types of aquaculture account for an important part of aquaculture production in the EU. The total EU-27 aquaculture production in 2018 was 1,167,494 tonnes live weight, of which 650,792 tonnes were shellfish, 92,723 tonnes cyprinids[5] and 14,588 tonnes finfish from estuaries and lagoons.

Both have a similar socio-economic component since micro and small companies, with family characteristics and strong roots in their territories, primarily harvest these species; both also produce nutritious foods whose regular consumption is recommended for a healthy diet[6].

In addition, some of this production is recognized through official quality-origin-tradition seals and is part of the rich and varied gastronomic heritage of the EU (Mexillón de Galicia, Moules de Bouchot, Cozza di Scardovari, Pohořelický Kapr, Tinca Gobba Dorata del Pianalto di Poirino, etc.).

2.1. Shellfish farming or bivalve aquaculture and shellfish waters

In the EU, there is extensive bivalve production (mainly mussels, oysters and clams) in which filter herbivorous species feed only on renewable nutrient material available in the natural environment. This production does not require manufactured feed, fertilizers, veterinary treatments or pesticides. For this reason, shellfish farming maintains a strong link with its natural environment.

In 2018, 60% of EU-27 aquaculture production was bivalves. The main mollusc-producing countries are Spain, Italy and France, and the main species are mussels, oysters and clams.

Spain is the largest producer of mussels, which are grown in its north-western area of Galicia using rafts. Others important mussel producers are the Netherlands, France and Ireland. Pacific cupped oysters are

[5] EU aquaculture: An economic analysis. Maritime economic papers nº 06/2019. Agriculture, Forestry and Fishery Statistics. 2020 edition, Eurostat.

[6] Shellfish and fish have similar health benefits; both are good source of nutrients (high-quality protein, minerals, low lipid content and, especially, a high proportion of polyunsaturated fatty acids). In the Wheel of Five it is recommended to eat fish – at least – once a week. Fish and shellfish fat belongs to the category of polyunsaturated fatty acids, specifically the omega-3 fatty acids eicosapentaenoic acid and docosahexaenoic acid. It has been scientifically proven that these fatty acids lower the risk of cardiovascular disease and have a beneficial effect on blood pressure.

The Health Council advises adults to average 200 milligrams of omega-3 fatty acids from fish per day. This recommendation can be met by eating one serving of fish, including shellfish, per week. Fish and shellfish contain a lot of animal protein and important B vitamins like B12 which are not found in plants. https://knowledge4policy.ec.europa.eu/health-promotion-knowledge-gateway/topic/food-based-dietary-guidelines-europe_en.

A.C. Wright, Y. Fan and G.L. Barker. (2018). Nutritional value and food safety of bivalve molluscan shellfish. *Journal of Shellfish Research* 37 (4), 695–708. https://doi.org/10.2983/035.037.0403.

produced mainly in France (about 86 % in 2018) and Ireland. Italy produces the vast majority (about 78% in 2018) of the EU's farmed Japanese carpet shells.

The mollusc farming methods developed in the EU are highly varied and adapted to the local environmental conditions and traditions (bateas, bouchots, vivai, bottom culture, longlines, etc.), which also protect the cultured bivalves' welfare. All farming occurs in the natural environment, taking advantage of the renewable nutritive material contained in the waters in the most efficient way since no food is provided. Cultured bivalves occupy lower trophic levels and feed only by filtering the renewable nutritive material contained in the waters, so this type of aquaculture is very energy and ecologically efficient in the use of natural resources for the production of high-quality animal protein[7].

The three main types of shellfish farming practiced in the EU are rafts and longlines, intertidal systems and bottom culture:

(a) Rafts and longlines are used in deeper waters, with the shellfish (mainly mussels) cultivated through the use of suspended ropes. The largest mussel farming in the EU is the traditional raft mussel culture in the coastal areas of Galicia in Spain;

(b) Inter-tidal shellfish culture takes place within intertidal areas, thus benefiting from relatively accessible land-based support and the dynamic physical environment of the land/water interface; it is one of the older, most traditional forms of aquaculture in the EU. Some examples of this type of culture are bouchot poles for mussel culture and the oyster culture system, with mesh bags attached to trestles;

(c) In bottom culture, the juvenile animals are placed or 're-laid' on a suitable substrate for on-growing. This form of aquaculture is often practised in shallow coastal or estuarine areas. This method is widely used in Italy in the production of clams, and the cultivation of mussels through this system also has a tradition in the Netherlands and Ireland.

Given that all bivalve aquaculture types involve activities that require low inputs, their negative impacts on the environment and environmental footprints are relatively small and reversible.

In this sense, Hall et al. (2011)[8] compare (at the coarsest scales) animal food production sectors and examine the environmental consequences of the production of one ton of animal protein in each system (see Table 1). They conclude that bivalve farming is the least ecologically demanding of the animal source

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[7] SAPEA. (2017). Foods from the oceans. Evidence Review Report No. 1. Informs the Scientific Advice Mechanism High-Level Group of Scientific Advisors. Scientific Opinion No. 3/2017.

[8] Hall, S.J., A. Delaporte, M.J. Phillips, M. Beveridge and M. O'Keefe. (2011). Blue frontiers: Managing the environmental costs of aquaculture. Penang, Malaysia: The WorldFish Center.

foods and provides an ecological service by removing nutrients. These groups are a particularly nutritious and environmentally sustainable option for consumers.

Table 1. Comparison at coarsest scale of certain sustainability indicators among animal protein production systems. Source: Brummett (2013)[9].

	Food conversion (kg feed/kg edible weight)	Protein efficiency (%)	N emissions (kg/ton protein produced)	P emissions (kg/ton protein produced)	Land (tons edible product/ha)	Comsumptive freshwater use (m^3/ton)
Beef	31.7	5	1,200	180	0.24–0.37	15,497
Chicken	4.2	25	300	40	1.00–1.20	3,918
Pork	10.7	13	800	120	0.83–1.10	4,856
Finfish (average)*	2.3	30	360	48	0.15–3.7	5,000
Bivalves	not feed	not feed	-27	-29	0.28–20.00	0

Note: Unfortunately, under this heading, the different types of fish production systems (extensive, semi-intensive and intensive) that have very different sustainability indicators are not differentiated.

Meanwhile, recent studies[10] on nutrient footprint and ecosystem services of carp production in European fishponds confirmed that the greenhouse gas emission intensity (GHG EI) of carp ponds in the EU is approximately four times lower than the average GHG EI of the EU livestock sector (large and small ruminants, poultry). Carp farming in fishponds is very close to a 'neutral' method of production, unlike other food production sectors, as shown by the authors cited in Fig. 1.

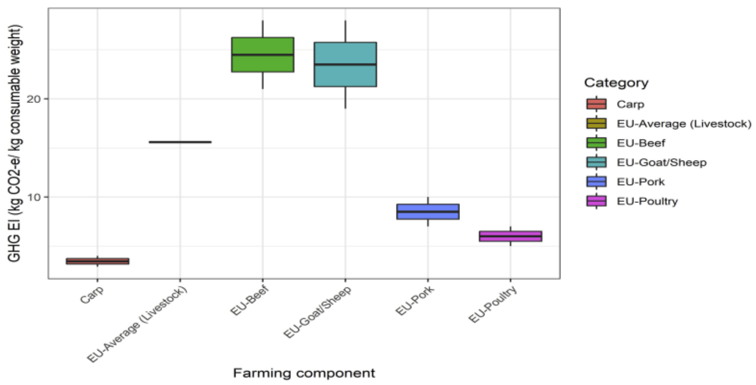

Fig. 1. GHG EI (kg CO_2-equivalent per kg consumable weight) of European livestock produced in comparison with farmed carp (Roy et al., 2020).

[9] R. Brummett. (2013, June). Growing aquaculture in sustainable ecosystems. Agriculture and Environmental Services Department; World Bank, Issue 5.

Bouwman, A.F., A.H.W. Beusen, C.C. Overbeek, D.P. Bureau, M. Pawlowski and P.M. Gilbert. (2013). Hindcasts and future projections of global inland and coastal nitrogen and phosphorus loads due to finfish aquaculture. *Reviews in Fisheries Science* 21 (2), 112–156.

[10] Roy, K., J. Vrba, S.J. Kaushik and J. Mraz. (2020). Nutrient footprint and ecosystem services of carp production in European fishponds in contrast to EU crop and livestock sectors: European carp production and environment. *Journal of Cleaner Production*, 270, 122268. https://doi.org/10.1016/j.jclepro.2020.122268.

Waite et al. (2014)[11] relate the effects of the intensity of aquaculture systems to their environmental performance in connection with several important inputs (land, freshwater, feed and energy), showing that extensive bivalve and fish aquaculture offers better environmental performance.

More recently, Hilborn et al. (2018)[12] reviewed 148 assessments of food production of animal origin (livestock, aquaculture and capture fisheries practices) that used four environmental impact metrics (energy use, greenhouse gas emissions, nutrient release and acidifying compounds) and examined additional literature on freshwater demand, pesticide use and antibiotic use. They conclude that the production methods (standardized per unit of protein production) with the lowest impact were small pelagic fishing and bivalve molluscs aquaculture: 'Though all food production has environmental cost, this differs greatly between different types of animal protein. The lowest impact forms of animal protein come from species that feed naturally in the ocean and that can be harvested with low fuel requirements'.

In the last year, Kim et al. (2020)[13] compared the greenhouse gas (GHG) and water footprints of various diets in 140 countries and conclude that in relation to exclusively plant-based (vegan) diets, those diets that consist of plant foods supplemented with low-food chain animals (forage fish, bivalve molluscs, insects) have comparatively small GHG and water footprints and offer greater flexibility, so they make up a healthy and sustainable diet.

Due to the strong link between mollusc aquaculture and the natural environment where it develops, shellfish farming requires the highest water quality to provide the best and safest products. For this reason, historical and present European water regulations require that the waters dedicated to shellfish farming be protected[14]. The area occupied by shellfish waters in the EU is more than 1,000 km^2 (Source: European Molluscs Producers Association), and states are required to maintain a registry of these waters

[11] Waite, R., M. Beveridge, R. Brummett, N. Chaiyawannakarn, S. Kaushik, R. Mungkung, S. Nawapakpilai and M. Phillips. (2014). Improving productivity and environmental performance of aquaculture. Working Paper, Creating a Sustainable Food Future, Installment Five. Washington, DC: World Resources Institute. https://www.wri.org/research/improving-productivity-and-environmental-performance-aquaculture.

[12] Hilborn, R., J. Banobi, S.J. Hall, T. Pucylowski and T.E. Walsworth. (2018). The environmental cost of animal source foods. *Frontiers in Ecology and the Environment* 16 (6), 329–335. https://doi.org/10.1002/fee.1822.

[13] Kim, B.F., R.E. Santo, A.P. Scatterday, J.P. Fry, C.M. Synk, S.R. Cebron, M.M. Mekonnen, A.Y. Hoekstra, S.de Pee, M.W. Bloem, R.A. Neff and K.E. Nachman. (2020). Country-specific dietary shifts to mitigate climate and water crisis. *Global Environmental Change* 62, 101926. https://doi.org/10.1016/j.gloenvcha.2019.05.010.

[14] 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. AAC Recommendation on the Specific Protection of Shellfish Water Quality 30/10/2019.

as special protection areas, define specific environmental objectives for these areas, evaluate compliance with these objectives and establish measures necessary to achieve these objectives.

2.2. Extensive and semi-intensive fish farming

These fish aquaculture practices are developed in different habitat types in the EU, but their common feature is that they function as constructed wetlands. As defined by the Convention on Wetlands of International Importance (Ramsar), wetlands include lakes and rivers, swamps and marshes, wet grasslands and peatlands, oases, estuaries, deltas and tidal flats, near-shore marine areas, mangroves and coral reefs and human-made sites such as fishponds, rice paddies, reservoirs and salt pans: 'As an integral part of the water cycle, wetlands are amongst the most productive ecosystems on earth and are of great economic and cultural importance to mankind'[15].

From an ecological point of view, there is no essential difference between extensive and semi-intensive aquaculture systems since both are based on natural processes. However, by the traditional, production-approach definition, in semi-intensive aquaculture the natural diet is supplemented with feed, normally prepared with local cereals and agricultural by-products, to supplement the intake of natural foods.

These fish farming activities require low levels of inputs, are strongly linked or integrated in the natural environment, have a low impact and generate positive effects on the ecosystem.

2.2.1. Fishpond Farming

Inland fish farming typically practiced in freshwater environments using earthen ponds (semi-natural systems) are the most common facility in most countries[16]. The total volume of EU-27 finfish freshwater aquaculture sales was 268 300 tonnes in 2018, generating a value of 812.4 million euros, with trout (58.3%) and carp (23.4%) the major species. Italy remains the largest contributor to the EU freshwater production, accounting for 13% of the volume and 12% of the value. Other major producers are Denmark, France and Spain, which are responsible for 11%, 9% and 6% of total EU production volume, respectively[17]. Traditional carp pond farming is concentrated in Central and Eastern European countries.

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[15] Shine, C. and C. de Klemm. (1999). *Wetlands, water and the law: Using law to advance wetland conservation and wise use*. Gland, Switzerland: International Union for Conservation of Nature.

[16] Food and Agriculture Organization (FAO). (2018). The state of world fisheries and aquaculture 2018 - Meeting the Sustainable Development Goals. Rome: FAO.

[17] Scientific, Technical and Economic Committee for Fisheries (STECF). (2018). Economic report of the EU aquaculture sector (STEFC–18–19). Luxembourg: Publications Office of the European Union. https://doi.org/10.2760/45076.

The main producers are Poland (28%), Czechia (25%), Hungary (15%), Bulgaria (6%), Germany (6%) and Romania (6%)[18].

A fishpond by definition means a human-made structure which can be fully filled and drained systematically through monks (a tall box with two sides, a back, a front formed by wooden boards and a bottom, each side having two slots to hold two rows of wooden boards used to control the amount of water coming in and going out of the pond) or other hydrotechnical structures. These systems replicate natural ecosystems and can thus be called semi-natural. Fishpond sizes vary widely. In Central and Eastern Europe, they are about 25–300 ha in average. There are two typical types: barrage ponds in hilly areas and paddy ponds, mainly in plain areas. Fishpond production is typically managed in polyculture, where the common carp is produced in combination with other fish species of the same age class (silver carp, grass carp, European Catfish, pikeperch and pike, etc.). The central element in pond production is the common carp. Fishpond production is either extensive or semi-intensive. In semi-intensive farming, the natural food sources – largely zooplankton – are complemented with cereals and supplementary feeding of plant-based feeds with high protein content (e.g., oil-extracted sunflower seeds, lupines, peas). The ratio of the yields received from natural food sources and from feeding varies significantly between farms, based on their specific conduct.

The European Parliament stressed in its resolution of June 2018, 'Towards a sustainable and competitive European aquaculture sector', that freshwater aquaculture is still an insufficiently explored opportunity for improving food security and developing rural areas[19]. On the other hand, biodiversity loss is one of the most critical environmental threats alongside climate change and the two are inextricably linked and the most recent Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) report[20] concluded that 'river and lake systems often sustain coastal wetlands which are hotspots of biological production and diversity in the landscape mosaic. Therefore, freshwater habitats contribute importantly to green corridors and networks'.

[18] FAO. (2020) Fishery and aquaculture statistics. Global aquaculture production 1950–2018 (FishstatJ). (2020). Rome: FAO Fisheries Division. www.fao.org/fishery/statistics/software/fishstatj/en.

[19] European Parliament. (2018, June 12). Resolution of 12 June 2018 towards a sustainable and competitive European aquaculture sector: Current status and future challenges (2017/2118(INI)). Brussels. http://www.europarl.europa.eu/doceo/document/TA-8-2018-0248_EN.pdf.

[20] M. Rounsevell, M. Fischer, A. Torre-Marin Rando, & A. Mader, Eds. (2018). The regional assessment report on biodiversity and ecosystem services for Europe and Central Asia. Bonn, Germany: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

2.2.2. Estuarine areas and lagoons

Lagoon culture is a traditional coastal aquaculture system that originated in the Mediterranean and uses coastal lagoons to capture migrating fish fry and grow them on for human consumption. Extensive fish culture has been a traditional activity in some saltmarsh areas in Europe, where farms may obtain a natural fry recruitment through adequate management of water inflow with the tides. For the purpose of this document, the generic term 'lagoon' includes all typologies: genuine lagoons, coastal lakes and ponds, *sacche (*bays*)*, delta areas and *valli*.

'The Mediterranean region hosts around 400 coastal lagoons, covering a surface of over 641 000 ha differing in both their typology and use. Fisheries and various forms of aquaculture have been traditionally carried out in Mediterranean coastal lagoons since ancient times and are part of the cultural heritage of the region. Traditional lagoon management linked to extensive aquaculture and fish harvesting has certainly contributed, over time, to preserve these peculiar ecosystems, although much of the coastal lagoon areas have progressively disappeared due to land reclamation and other uses.'[21]

The most iconic lagoons of the Mediterranean are the valli*,* found in the Northern Adriatic in the Friuli Venezia Giulia, Veneto and Emilia Romagna regions and defined by earthen embankments, sluice gates, internal canalization, basins for fish collection and wintering and fish barriers. *Vallicultura* refers to the traditional management model carried out in the northern Adriatic valli, based on hydraulic management, dredging, enhancing fisheries by stocking and fish capture, that was developed by the Etruscan civilization in the sixth century BC mainly in the Po and Adige estuaries.

The loss of lagoon areas and many freshwater ponds took place in the nineteenth century as a result of land reclamation by agriculture which, in the context of the Industrial Revolution and the process of urbanization, was perceived as more profitable than fisheries and aquaculture. Many lagoon areas were maintained throughout the centuries by traditional management at the local level, safeguarding not only economic activities but also biodiversity.

Even if lagoon science is quite new, steady progress has been made in recent years to achieve an accurate image of its ecological complexity. The key factor in lagoon sustainability is the presence of seaweeds and seagrasses that play an important role in ensuring ecosystem functioning, in providing a functional habitat and in biogeochemical processes. Seagrasses and seaweeds are an important source of biomass for the production of paper and manure for agriculture and in the chemical and

[21] Cataudella S., D. Crosetti and F. Massa, Eds. (2015) Mediterranean coastal lagoons: Sustainable management and interactions among aquaculture, capture fisheries and the environment. Studies and Reviews. General Fisheries Commission for the Mediterranean. No 95. Rome: FAO.

pharmaceutical industries. Lagoons are also rich in benthic communities (phytobentos and zoobenthos) that provide proper reproduction, feeding and growing areas for different fish species and shellfish while attracting hundreds of bird species.

Artisanal fishing and aquaculture have a millennial tradition in these ecosystems and are already part of the ecosystem services mechanisms; they should therefore be used as a management model in the lagoons. A broad range of management practices have been maintained along traditional lines or have evolved into a multifunctional approach integrating fisheries and aquaculture with tourism, nature conservation and recreational activities and involving all stakeholders, especially fishers and aquaculture famers. These traditional approaches have maintained or restored the ecological integrity of coastal lagoons, thus offering the possibility that lagoon ecosystems can provide ecological services. It can be concluded that fish production in every type of lagoon area in Italy, Spain, France or Greece has historically contributed to the conservation of these semi-natural environments.

3. Evolution of the conceptual framework of ecosystem services

The concept of services provided by nature began to take shape in the 1960 and 1970s, before the verification of a situation of increasing and intense degradation of the natural environment. In the early 1980s, the term 'ecosystem services'[22] was coined to emphasize the close relationship and interdependence that exists between human well-being and the well-being of natural ecosystems.

Over the years, this concept has evolved and been enriched by different disciplines of knowledge, especially economics. Thus, various authors have tried to quantify the value or importance of the services that nature provides to humans on a monetary basis, trying to build a tool that would enable better decision-making in the search for truly sustainable development. This, according to several thinkers, has led to a commodification of these services, which can be counterproductive in the search for the preservation of biodiversity[23]. Faced with these criticisms, new approaches are emerging to determine the 'value' rather than the price of nature[24].

Table 2 shows some of the most commonly used definitions of 'ecosystem services' to illustrate the evolution of this concept. At present, the notion of ecosystem services is considered a useful tool that provides an effective framework for public authorities to promote sustainable development that includes the preservation of natural biodiversity.

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[22] Ehrlich, P.R. and A. Ehrlich. (1981). *Extinction: The causes and consequences of the disappearance of species*. New York: Random House.

[23] Gómez-Baggethun, E., R.S. de Groot, P.L. Lomas and C. Montes. (2010). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics* 69 (6), 1209–1218. https://doi.org/10.1016/j.ecolecon.2009.11.007.

Braat, L.C. and R.S. de Groot. (2012). The ecosystem services agenda: Bridging the worlds of natural science and economics, conservation and development, and public and private policy. *Ecosystem Services* 1, 4–15. https://doi.org/10.1016/j.ecoser.2012.07.011.

[24] Sander, J., N. Dendoncker, B. Martín-López, D.N. Barton, E. Gomez-Baggethun, F. Boeraeve, F.L. McGrath L., K. Vierikko, D. Geneletti, K.J. Sevecke, N. Pipart, E. Primmer, P. Mederly, S. Schmidt, A. Aragão, H. Baral, R.D. Bark, T. Briceno, D. Brogna, P. Cabral, R. De Vreese, C. Liquete, H. Mueller, KS.-H. Peh, A. Phelan, and A. Rincón Ruíz. (2016). A new valuation school: Integrating diverse values of nature in resource and land use decisions. *Ecosystem Services* 22, Part B: 213–220. https://doi.org/10.1016/j.ecoser.2016.11.007.

Sukhedev, P., H. Wittmer and D. Miller. (2014). The economics of ecosystems and biodiversity (TEEB): Challenges and responses. In *Nature in the balance: The economics of biodiversity* (D. Helm and C. Hepburn, Eds.). Oxford: Oxford University Press, pp. 135–150.

Spangenberg, J.H. and J. Settele (2010). Precisely incorrect? Monetising the value of ecosystem services. *Ecological Complexity* 7 (3), 327–337. https://doi.org/10.1016/j.ecocom.2010.04.007.

Table 2. Some definitions of ecosystem services.

The definition of 'ecosystem services' has evolved through various publications, with differing attention to its ecological basis or its economic use:

- Ecosystem functions are 'the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly' – De Groot, 1992
- Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life – Daily, 1997.
- Ecosystem services are the benefits human populations derive, directly or indirectly, from ecosystem functions – Costanza et al., 1997.
- Ecosystem services are the benefits people obtain from ecosystems – Millennium Ecosystem Assessment, 2003, 2005.
- Ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well-being – Boyd and Banzhaf, 2007.
- Ecosystem services are the aspects of ecosystems utilised (actively or passively) to produce human well-being – Fisher et al., 2009.
- Ecosystem services are the direct and indirect contributions of ecosystems to human well-being – TEEB Foundations, 2010.
- Ecosystem services are the contributions that ecosystems make to human well-being. This definition distinguishes the goods and benefits that people subsequently derive from them. These contributions are framed in terms of 'what ecosystems do' for people – CICES, 2012.
- Ecosystem services: the contributions of ecosystems to benefits obtained in economic, social, cultural and other human activity (based on TEEB, 2010 and SEEA-EEA, 2012). The concepts of 'ecosystem goods and services', 'final ecosystem services' and 'nature's contributions to people' are considered to be synonymous with ecosystem services – SWD (2019) 305 Part 1/3

A key moment in the placement of this concept on the public agenda occurred at the beginning of this century in the initiative promoted by the United Nations known as the Millennium Ecosystem Assessment (MEA, 2005). After more than 10 years, numerous initiatives have advanced the knowledge of ecosystem services and in the development of tools based on ecosystem services as mechanisms to correct the loss of biodiversity. Of particular note are the TEEB initiative in 2010 (a global initiative to study the economics of ecosystems and biodiversity) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) since 2012.

In the EU, the adoption of this conceptual framework has been reinforced and integrated into a growing number of Community policies[25]. In 2011, with the adoption of the Biodiversity Strategy to 2020, the EC highlighted, for the first time, the immense value of ecosystem services and the urgent need to maintain and restore them for the benefit of both nature and society. As part of this strategy, the Biodiversity Information System for Europe (BISE), the System of European Biodiversity Indicators (SEBI) and the Mapping and Evaluation of Ecosystems and their Services (MAES) were created[26].

As with its definition, there is no single classification of ecosystem services. The most widely used categorization comes from the MEA (2005), in which ecosystem services are grouped into four categories: supply, regulation, cultural and support.

- *Supply Services* are the products we obtain from ecosystems (food, fresh water, fibres, wood, etc.);
- *Regulation Services* are the benefits obtained from the regulation of ecosystem processes (climate regulation, crop pollination, disease control, etc.);
- *Cultural Services* are the intangible benefits that we obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences;
- *Support Services* are those necessary for the production of the above ecosystem services (offering spaces in which plants and animals live, or allowing species diversity and maintaining genetic diversity).

Later, TEEB, IPBES and other institutions have offered new classifications for ecosystem services that feature certain differences with the MEA. As a consequence of the work on environmental accounting carried out by the European Environment Agency, a Common International Classification of Ecosystem

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[25] Bouwma et al. (2018) analyse how this concept has gained a presence in EU policies. Bouwma, I., C. Schleyer, E. Primmer, K.J. Winkler, P. Berry, J. Young, E. Carmen, J. Špulerová, P. Bezák, E. Preda and A. Vădineanu. (2018). Adoption of the ecosystem services concept in EU policies. *Ecosystem Services* 29, Part B, 213–222. https://doi.org/10.1016/j.ecoser.2017.02.014.

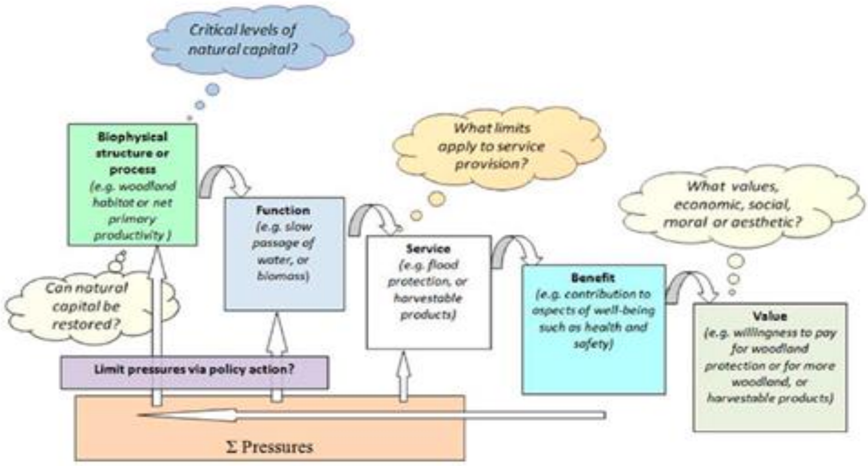
Another milestone that shows the clear adoption of this conceptual framework in the EU is the recent publication of the 'Commission Staff Working Document: EU Guidance on integrating ecosystems and their services into decision-making' (SWD(2019) 305 final).

[26] Maes, J., B. Egoh, L. Willemen, C. Liquete, P. Vihervaara, J.P. Schägner; B. Grizzetti, E.G. Drakou, A. La Torre, G. Zulian, F. Bouraoui, M.L. Paracchini, L. Braat and G. Bidoglio (2012). Mapping ecosystem services for policy support and decision making in the European Union. *Ecosystem Services* 1, 31–39. https://doi.org/10.1016/j.ecoser.2012.06.004.

Services (CICES)[27] has been developed. From the perspective of environmental accounting, intermediate ecosystem services (those that report indirect benefits) are distinguished from final ecosystem services (those that report direct benefits). Following the logic of the CICES, the support services (intermediate ecosystem services) are inputs to other services, so intermediate ecosystem services should not be included in the valuation systems to avoid the problem of double counting. It is also important to highlight that habitats and animals themselves, summarized in a separate category called 'habitat services' in the TEEB categorization system, are not qualified as ecosystem services in CICES. Instead, they are used as ecological indicators that show the state of an ecosystem and its service-providing capabilities.

CICES uses the Potschin and Haines-Young waterfall scheme, so its classification is based on human interests, offering a clear structure that allows the analysis of the consequences of ecosystem management on the well-being of humanity.

Potschin and Haines-Young (2011)[28] made an important contribution to the conceptualization of ecosystem services from the field of geography. Their waterfall scheme integrates the environment into the socio-economic system, establishing a connection between the structures, processes and functions of ecosystems with human well-being through final ecosystem services. The last link in this cascade is the value or importance that humans attach to the benefits that ecosystems provide us.



[27] Haines-Young, R. and M. Potschin (2018). Common International Classification of Ecosystem Services (CICES) V5.1: Guidance on the Application of the Revised Structure.

[28] Potschin, M.B. and R.H. Haines-Young (2011). Ecosystem services: Exploring a geographical perspective. *Progress in Physical Geography* 35 (5), 575–594. https://doi.org/10.1177%2F0309133311423172.

In summary, the CICES classification divides the services provided by ecosystems into three categories: provisioning, regulating and cultural services.

- *Provisioning Services* are related to the capacity of ecosystems to provide us with nutrients, materials and energy.
- *Regulating and Maintenance Services* include those for the remediation of waste, toxic substances and other materials, those for the regulation of flows and those that have to do with the maintenance of physical, chemical and biological conditions.
- *Cultural Services* correspond to physical and intellectual interactions with the environment, along with spiritual and symbolic interactions.

Another principle in CICES is that it is not just natural ecosystems that provide ecosystem services; semi-natural ecosystems and highly modified ones can also do so. This type of ecosystem, in which human beings have a marked participation, are tributaries of the ecosystem resources provided by nature, but at the same time, if they are properly managed, participate in the generation of ecosystem resources with a positive balance.

That is, it is recognized that certain human activities, well managed from an environmental perspective, are generators of ecosystems and landscapes that enrich the biodiversity and ecosystem services available in a given territory.

The conceptual system of ecosystem services, as well as the different tools that are being developed and standardized, is a crucial technique for the evaluation and analysis of human practices and 'human ecosystems' to ensure that both favour, or ideally guarantee, human well-being by helping preserve biodiversity.

4. Socio-ecosystems and their ecosystem services

A first important question when studying and evaluating ecosystem services has to do with the identification of natural ecosystems and, by extension, socio-ecosystems. Regarding the latter, the natural value of certain ecological systems that are closely linked to humans, who modulate those systems, has long been recognized.

As a result of human-nature interaction, humanized ecosystems are generated, benefit from ecosystem services and, in turn, provide benefits to ecosystems. Those humanized ecosystems produced by a harmonious interaction between people and nature are more resilient, enrich biodiversity and, through the ecosystem services they produce, maximize benefits for society.

Understanding, recognizing and valuing these unique socio-ecosystems oriented towards food production and the generation of services, in which small family businesses strongly linked to the territory carry out sustainable production practices, will contribute to redirecting food systems within safe planetary limits and to healthier, more diverse and more equitable diets.

Furthermore, the study and analysis of the ecosystem services of these socio-ecosystems will make it possible to define practices that maximize benefits and determine and correct erroneous practices that can negatively affect biodiversity and human well-being.

Ecosystems originated by agricultural and forestry activities, or agro-ecosystems, are ecosystems created by humanity for the production of food and fibres and have long been known and studied. Among those derived from extensive agricultural practices, agricultural practices of high natural value (which minimize the use of manufactured inputs such as pesticides and fertilizers) are recognized as generators of numerous ecosystem services; their protection and valorization are promoted, supporting the people that maintain them through global initiatives such as the one developed by the Food and Agriculture Organization (FAO), an agency of the United Nations[29].

In addition, the FAO also regards[30] the evaluation and valuation of ecosystem services as important initial steps to recognizing the extent to which ecosystem services contribute to agriculture, livestock and fisheries (and vice versa) and thus to national economies. Knowing the value of ecosystem services encourages greater investment in their management. Furthermore, society (the direct and indirect beneficiaries) has to compensate for environmental damage (e.g., pollution) and remunerate farmers for improving ecosystem services and biodiversity, which would create value for these services.

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[29] The FAO recognizes diverse and locally adapted farming systems and has managed them with ingenious techniques and practices that they have refined over the years. 'Globally Important Agricultural Heritage Systems' (GIAHS) are outstanding landscapes of aesthetic beauty that combine agricultural biodiversity, resilient ecosystems and a valuable cultural heritage. Located at specific sites around the world, they sustainably provide multiple goods and services, food and livelihood security for millions of small-scale farmers.

[30] http://www.fao.org/ecosystem-services-biodiversity/valuation/en/

Developing incentive packages requires input from many sectors; such incentives can be regulatory (such as granting permits and quotas) or voluntary (such as improving market access, labelling or certification of products)[31].

The same recognition does not apply to the ecosystems generated by aquaculture. The proof of this is that the European Habitats Identification and Classification System (EUNIS)[32] recognizes agricultural habitats but does not identify aquaculture habitats.

When the second report of *Mapping and assessment of ecosystems and their services: Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020*, discusses freshwater and marine ecosystem services, it examines only rivers, lakes and small bodies of water; neither ponds nor the aqua-ecosystems of extensive cultivation of bivalves are ever mentioned.

This is so even though the polyculture of carps and associated species in earthen ponds is an important source of biodiversity upkeep. The abandonment in recent years of some of these fish farms was followed by the loss of biodiversity in the area in the form of plants, birds and mammals. Research carried out in the last few years identified 41 potential ecosystem services (10 provisioning, 20 regulating and maintenance, 11 cultural) that aqua-ecosystems can provide[33].

Table 3 – Potential ecosystem services provided by aqua-ecosystems (Willot et al., 2019)

Ecosystem services	Section	Group	Class
Provisioning	Nutrition	Biomass	Wild animals and their outputs
			Animals from in situ aquaculture
			Plants and algae from in situ aquaculture
		Water	Surface water for drinking
	Materials	Water	Surface water for non-drinking purposes
		Biomass	Materials from plants, algae and animals for agricultural use
			Genetic materials from all biotas
			Fibre and other materials from plants, algae and animals for direct use or processing

[31] http://www.fao.org/ecosystem-services-biodiversity/background/en/.

[32] https://eunis.eea.europa.eu/habitats-code-browser.jsp?expand=#level_A.

[33] Willot, P.-A., J. Aubin, J.-M., Salles and A. Wilfart. (2019). Ecosystem service framework and typology for an ecosystem approach to aquaculture. *Aquacultures* 512, 734260. https://doi.org/10.1016/j.aquaculture.2019.734260.

Table 3 – Potential ecosystem services provided by aqua-ecosystems (Willot et al., 2019)

Ecosystem services	Section	Group	Class
	Energy	Biomass-based energy sources	Plant-based resources
			Animal-based resources
Regulation and maintenance	Mediation of waste, toxins and other nuisances	Mediation via biota	Bio-remediation via micro-organisms, algae, plants and animals
			Filtration, sequestration, storage and accumulation via micro-organisms, algae, plants and animals
		Mediation via ecosystems	Filtration, sequestration, storage and accumulation via ecosystems
			Dilution via the atmosphere, freshwater and marine ecosystems
	Mediation of flows	Mass flows	Mass stabilization and control of erosion rates
			Buffering and attenuation of mass flows
		Liquid flows	Hydrological cycle and water flow maintenance
			Flood protection
		Gas/air flows	Storm protection
			Ventilation and transpiration
	Maintenance of physical, chemical and biological conditions	Lifecycle maintenance, protecting habitats and gene pools	Pollination and seed dispersal
			Maintaining nursery populations and habitats
		Pest and disease control	Pest control
			Disease control
		Soil formation and composition	Weathering processes
			Decomposition and fixing processes
		Water conditions	Chemical condition of freshwater
			Chemical condition of saltwater
		Atmospheric composition and climate regulation	Global climate regulation by reducing greenhouse gas concentrations
			Micro-climate and regional climate regulation
Cultural	Physical and intellectual interactions with biota, ecosystems and land- and seascapes	Physical and experiential interactions	Experiential use of plants, animals and land- and seascapes in environmental settings
			Physical use of land- and seascapes in environmental settings
		Intellectual and representative interactions	Entertainment
			Scientific
			Educational
			Aesthetic
			Heritage, cultural
	Spiritual, symbolic and other interactions	Spiritual and/or emblematic	Symbolic
			Sacred and/or religious
		Other cultural outputs	Existence
			Bequest

Table 3 – Potential ecosystem services provided by aqua-ecosystems (Willot et al., 2019)			
Ecosystem services	Section	Group	Class
	with biota, ecosystems and land- and seascapes		

4.1. Aqua-ecosystems of extensive cultivation of bivalves and the ecosystem services they provide

For years, it has been recognized that certain organisms have a significant capacity to modify the environment that surrounds them physically, biologically or chemically. These 'ecosystem engineers' modulate the environment, influencing biodiversity and the heterogeneity of the landscape in a given area.

The dense aggregations of filter feeder sedentary benthic bivalves common in many shallow water environments are one such example. Typically called reefs or bivalve beds, these systems often serve such important structural and functional uses in ecosystems that they are often classified as ecosystem engineers[34]. In addition, these natural aggregates of bivalves[35] have been recognized as an ecosystem that generates ecosystem services[36].

Bivalves play a vital role in influencing or even controlling processes such as bioturbation and water filtration that sustain marine food webs and biodiversity, as well as driving the biogeochemical cycle and modifying the erodibility of sediments. Bivalve aggregates provide a structural habitat that supports a wide range of other species.

In the same way, in areas where aggregated bivalves of molluscs are cultivated, they also constitute ecosystems with human intervention – aqua-ecosystems for food production – which provide ecosystem

[34] Jones, C.G., J.H. Lawton and M. Shachak. (1994). Organisms as ecosystem engineers. *Oikos* 69, 373–386.

[35] Dame, R.F. (1996). *Ecology of marine bivalves: An ecosystem approach*. Boca Raton, FL: CRC Press.

[36] Ysebaert, T., B. Walles, J. Haner and B. Hancock. (2018). Habitat modification and coastal protection by ecosystem-engineering reef-building bivalves. In *Goods and services of marine bivalves* (A.C. Smaal, J.G. Ferreira, J. Grant, J.K. Petersen and Ø. Strand, Eds.). Cham, Switzerland: Springer, pp. 253–273.

services. In this case, it must be borne in mind that the aggregates of molluscs are managed by shellfish farmers and that in these aqua-ecosystems (registered as shellfish waters), the generation of food is maximized (provisioning services) over other services (for example, the service of limiting coastal erosion). Extensive aquaculture practices for bivalve rearing are characterized by a high degree of dependence on natural functioning and a low level of intervention.

Several recent texts review the scientific studies related to the ecosystem services supplied by both the natural beds of bivalves and the aquaculture of molluscs[37].

As regards bivalve rearing, the first ecosystem service it generates is the supply of natural foods. Although made of other materials, bivalve shells can be used in a variety of ways and have a numerous benefits[38]:

- Support services such as the creation of habitats rich in biodiversity that are attractive to predators like seabirds and carnivorous fish;

Regulating services: regulation of nutrient fluxes (reduction of eutrophication), improvement of water quality, carbon sequestration by shells (although there is no consensus in the scientific community on this service[39]), improvement of seagrass growth and macroalgae and so on. In some areas, the potential

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[37] Northern Economics, Inc. (2012). Valuation of ecosystem services from shellfish restoration, enhancement: A review of the literature. Prepared for NOAA National Ocean Services: EPA REServ Program.

Smaal, A. C., Ferreira, J. G., Grant, J., Petersen, J. K. and Strand, Ø., Eds. (2018). *Goods and services of marine bivalves*. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-96776-9.

van der Schatte Olivier, A., L. Jones, L. Le Vay, M. Christie, J. Wilson and S.K. Malham. (2018). A global review of the ecosystem services provided by bivalve aquaculture. *Reviews in Aquaculture* 12, 3–25 https://doi.org/10.1111/raq.12301.

McLeod, D.A. & C. McLeod. (2019). Review of the contribution of the contribution of cultivated bivalve shellfish to ecosystem services. A review of the scientific literature commissioned by Crown Estate Scotland.

Systema Environnement-Agnès Pouliquen (2019). Les services écosystémiques de la conchyliculture. CRC Bretagne-Nord; pp 80. https://www.wikimer.org/wp-content/uploads/2021/03/Ecosyst%C3%A9mie%20RAPPORT%20FINAL.pdf

[38] K.N. Kelley (2009). Use of recycled oyster shells as aggregate for previous concrete. Master’s thesis. University of Florida, Gainesville, FL.

[39] Filgueira, R., T.Strohmeier and Ø. Strand. (2019). Regulating services of bivalve molluscs in the context of the carbon cycle and implications for ecosystem valuation. In *Goods and services of marine bivalves* (A.C. Smaal, J.G. Ferreira, J. Grant, J.K. Petersen and Ø. Strand, Eds.). Cham, Switzerland: Springer, pp. 231–251.

Moore, D. (2020). A biotechnological expansion of shellfish cultivation could permanently remove carbon dioxide from the atmosphere. *Mexican Journal of Biotechnology* 5 (1), 1–10. https://doi.org/10.29267/mxjb.2020.5.1.1.

for nitrogen and phosphorus withdrawal from eutrophic coastal waters has been recognized as a transactional ecosystem service through various forms of Payment for Ecosystem Services schemes[40];

- Cultural services: generation of unique local landscapes, contribution to identity in places where these activities are traditional, increase in attractive tourist sites and so on.

Among the ecosystem services that these aqua-ecosystems generate, the ability of farming bivalves to absorb nitrogen, phosphorous and carbon emissions from other systems stands out. Therefore, this type of aquaculture fits perfectly with the European Green Deal that seeks production systems with low carbon footprints that are efficient in their use of natural resources, which helps reduce coastal eutrophication.

Some examples of the potential mitigation effects on climate change (carbon sink) and eutrophication (absorbing nitrogen and phosphorous) of the aqua-ecosystems of extensive cultivation of bivalves are as follows:

- Manila clam aquaculture production in the Sacca di Goro lagoon (Italy)[41] has a net sequestration of 444.55 kg of CO_2, 1.54 kg of N and 0.31 kg of P per year;
- Nielsen et al. (2016)[42] estimate that a mussel production area in a Danish eutrophic fjord (18.8 ha) removes 0.6–0.9 tonnes of N ha^{-1} $year^{-1}$;
- Ferreira et al. (2007)[43] estimate that a ∼0.61-hectare (1.5-acre) oyster farm bottom culture would achieve a net removal of 9.7 tonnes of N per year.

[40] Petersen, J.K., B. Hasler, K. Timmermann, P. Nielsen, D.B. Tørring, M.M. Larsen and M. Holmer. (2014). Mussels as a tool for mitigation of nutrients in the marine environment. *Marine Pollution Bulletin* 82, 137–143. https://doi.org/10.1016/j.marpolbul.2014.03.006.

Rose, J.M., S.B. Bricker, M.A. Tedesco and G.H. Wikfors. (2014). Role for shellfish aquaculture in coastal nitrogen management. *Environmental Science & Technology* 48, 2519–2525. https://doi.org/10.1021/es4041336

[41] Turolla, E., G. Castaldelli, E.A. Fano and E. Tamburini. (2020). Life cycle assessment (LCA) proves that Manila clam farming (*Ruditapes Philippinarum*) is a fully sustainable aquaculture practice and a carbon sink. *Sustainability* 12 (13), 5252–5263. https://doi.org/10.3390/su12135252.

[42] Nielsen, P., P.J. Cranford, M. Maar and J.K. Petersen. (2016). Magnitude, spatial scale and optimization of ecosystem services from a nutrient extraction mussel farm in the eutrophic Skive Fjord, Denmark. *Aquaculture Environment Interactions* 8, 311–329. https://doi.org/10.3354/aei00175.

[43] Ferreira, J.G., A.J.S. Hawkins and S.B. Bricker. (2007). Management of productivity, environmental effects and profitability of shellfish aquaculture: The Farm Aquaculture Resource Management (FARM) model. *Aquaculture* 264, 160–174. https://doi.org/10.1016/j.aquaculture.2006.12.017.

Ferreira and Bricker (2016)[44] report the annual European bivalve shellfish production of over 700,000 tonnes is estimated to generate a nitrogen removal of 46,800 tonnes year^{-1}, equivalent to 14 × 10^6 population equivalent, and a minimum value of 507 million euros.

Regarding its role in strengthening biodiversity, shellfish culture modifies the structure of the local habitat and fauna and flora communities. Their introduction into the open sea and on the foreshore of cultivation structures and shells provides new habitat. The shells of bivalves and culture structures are colonized by epibenthic species: barnacles, bryozoans, ascidians, sponges, macroalgae and so on, and wildlife finds food and shelter in shellfish culture areas. This aquaculture promotes the development of diverse and more productive animal and plant communities that are comparable to those of natural bivalve reefs[45].

As for cultural services, estimating the significance of extensive shellfish farming is not easy. Briefly, however, mollusc aquaculture is part of the cultural heritage of several European regions, with practices typical of the territory and gastronomic festivities that have long traditions. In addition, bivalve production areas such as the raft polygons in Galicia or the bouchots in Normandy are part of the rich heritage of European landscapes. Bivalves are a recognized component of cultural tourism, and in some

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[44] Ferreira, J.G. and S.B. Bricker. (2016). Goods and services of extensive aquaculture: Shellfish culture and nutrient trading. *Aquaculture International* 24, 803–825. https://doi.org/10.1007/s10499-015-9949-9.

[45] Iglesias, J. (1981). Spatial and temporal changes in the demersal fish community of the Ría de Arousa (NW Spain). *Marine Biology* 65, 199–208. https://doi.org/10.1007/BF00397086.

Romero, P., E. Gozalez-Gurriarán and E. Penas. (1982). Influence of mussel rafts on spatial and seasonal abundance of crabs in the Ría de Arousa, NW Spain. *Marine Biology* 72 ,201–210. https://doi.org/10.1007/BF00396921.

Fernández, L., J. Freire and E. González-Gurriarán. (1995). Diel feeding activity of demersal fishes in the Ría de Arousa (Galicia, NW Spain): An area of intense mussel raft culture. *Cahiers de Biologie Marine* 36, 141–151. http://dx.doi.org/10.21411/CBM.A.EF69AA4C.

Freire, J. and E. González-Gurriarán. (1995). Feeding ecology of the velvet swimming crab *Necora puber* in mussel raft areas of the Ría de Arousa (Galicia, NW Spain). *Marine Ecology Progress Series* 119, 139–154. https://www.int-res.com/articles/meps/119/m119p139.pdf.

McKindsey C.W., P. Archambault, M.D. Callier and F. Olivier. (2011) Influence of suspended and off-bottom mussel culture on the sea bottom and benthic habitats: A review. *Canadian Journal of Zoology* 89, 622–646. https://doi.org/10.1139/z11-037.

Díaz López, B. and S. Methion. (2017). The impact of shellfish farming on common bottlenose dolphins’ use of habitat. *Marine Biology* 164, 83. https://doi.org/10.1007/s00227-017-3125-x.

Callier, M.D., C.J. Byron, D.A. Bengtson, P.J. Cranford, S.F. Cross, U. Focken, H.M. Jansen, P. Kamermans, A. Kiessling, T. Landry, F. O’Beirn, E. Petersson, R.B. Rheault, Ø. Strand, K. Sundell, T. Svåsand, G. H. Wikfors, C.W. McKindsey. (2018). Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: A review. *Reviews in Aquaculture* 10, 924–949. https://doi.org/10.1111/raq.12208.

Craeymeersch, J.A. and H.M. Jansen. (2019) Bivalve assemblages as hotspots for biodiversity. In *Goods and services of marine bivalves* (A.C. Smaal, J.G. Ferreira, J. Grant, J.K. Petersen and Ø. Strand, Eds.). Cham, Switzerland: Springer, pp. 275–294. https://doi.org/10.1007/978-3-319-96776-9_14.

European regions there is a strong tradition of bivalve eating. Some of these bivalves are recognized as unique foods within the European quality system, based on their origin. Finally, one of the symbols of Europe is the scallop (the symbol of St James), an emblem carried by pilgrims on their way to the shrine of Santiago de Compostela.

Recent studies have evaluated[46] and valued[47] all the benefits of the ecosystem services of bivalve aquaculture. They show that some of the non-commercial services may be worth at least more than half of the global production value and acknowledge that the true value of these non-commercial services is likely to be much higher, although they are not easily quantified.

In summary, extensive cultivation of bivalve molluscs are generators of aquaculture-ecosystems that report ecosystem services and enrich the productive and landscape diversity of the EU.

Fig. 3. Bottlenose dolphins jumping inside a raft mussel area in Galicia. Photo credit: Bottlenose Dolphin Research Institute (BDRI).

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[46] Gentry, R.R., H.K. Alleway, M.J. Bishop, C.L. Gillies, T. Waters and R. Jones. (2019). Exploring the potential for marine aquaculture to contribute to ecosystem services. *Review of Aquaculture* 12 (2), 499–512. https://doi.org/10.1111/raq.12328.

[47] van der Schatte Olivier, A., L. Jones, L. Le Vay, M. Christie, J. Wilson and S.K. Malham. (2018). A global review of the ecosystem services provided by bivalve aquaculture. *Review of Aquaculture* 12 (1), 3–25. https://doi.org/10.1111/raq.12301.

Fig. 4. (a) Mussel rafts in Galicia (Spain) are a privileged perch for seabirds. Photo credit: Xoán Diéguez; (b) Mussel culture in Sacca di Scardovari (Italy). Photo credit: Roberto Trombetta.

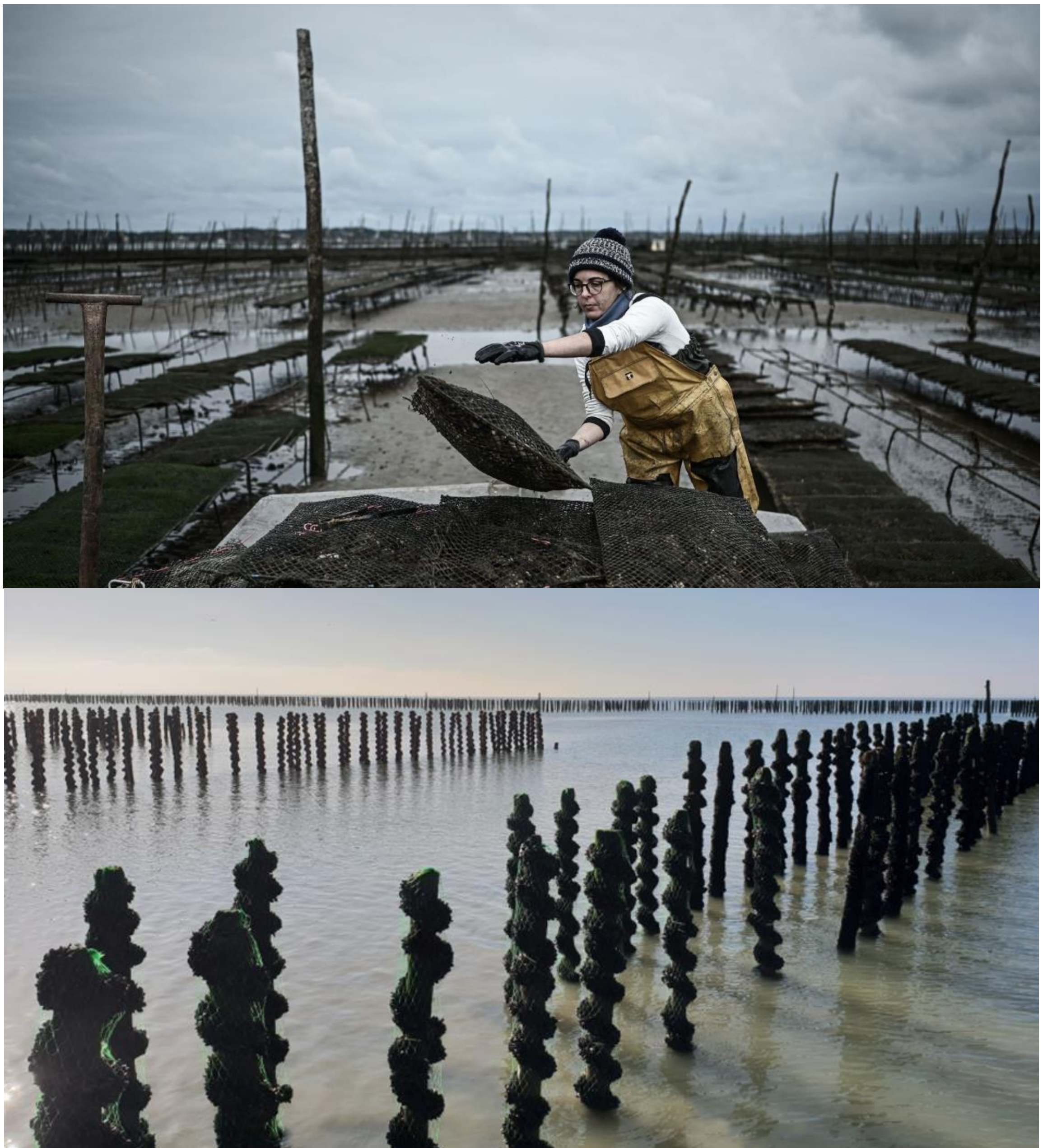

Fig. 5. (a) Anne Marquet in her oyster bed off the coast of La Teste-de-Buch (France). Photo credit: ©Philippe LOPEZ; (b) Mussel farming in the Pays de la Loire . Photo credit: ©CRC Pays de la Loire – A. Lebourg.

4.2. Wetlands and fishpond farming aqua-ecosystems and the ecosystem services they generate

The semi-natural wetlands and ponds (fish farming ecosystems) that developed in direct connection with fishpond farming mainly used for carp and associated species have a long history that dates back more than a thousand years[48]; for this reason, there is a public perception that they are not human-made but natural wetlands.

Fig. 6. Characteristic fishpond unit with large surface for carp production in Hortobágy, Hungary. Photo credit: ©Béla Halasi-Kovács.

Both natural and semi-natural wetlands are particularly important for carbon sequestration[49]. They also provide a wide range of other services such as flood defence, and water provisioning, management and purification while offering recreational and tourism opportunities[50]. A significant number of birds and mammals depend on freshwater wetlands for breeding or feeding[51]; wetlands are some of the planet's most productive ecosystems[52].

[48] Nash, C. E. (2011). *The history of aquaculture*. Ames, IA: Wiley-Blackwell.

[49] Cavallaro, N., G. Shrestha, R. Birdsey, M. A. Mayes, R. G. Najjar, S. C. Reed, P. Romero-Lankao and Z. Zhu, Eds. (2018). *Second state of the carbon cycle report (SOCCR2): A sustained assessment report*. Washington, DC: U.S Global Change Research Program (USGCRP).

[50] Villa, J. and B. Bernal. (2018). Carbon sequestration in wetlands, from science to practice: An overview of the bio-geochemical process, measurement methods, and policy framework. *Ecological Engineering* 114, 115–128. https://doi.org/10.1016/j.ecoleng.2017.06.037.

[51] BirdLife International. (2018). *State of the world's birds: Taking the pulse of the planet*. Cambridge: BirdLife International.

[52] Schlesinger, W.H. and E.S. Bernhardt. (2013). *Biogeochemsitry: An analysis of global change* (3rd ed.). Boston, MA: Academic Press.

Fig. 7. Traditionally, ponds are fished in autumn or early spring; carp farming in Waldviertel in north-western Austria. Photo credit: ©Florian Kainz/Archiv Aqua.

Fig. 8. Carp ponds also contribute to wetland preservation; Larga Jijia Ramsar site, Romania. Photo credit: ©ROMFISH.

The area occupied by pond aquaculture in EU is around 360,000ha[53]; most of the pond aquaculture farms were included in the Natura 2000 ecological network because they satisfied the requirements for quantitative and qualitative data. This was the first step in the indirect recognition of one service that these types of aquaculture provide to biodiversity protection objectives. These ponds are the backbone of the Natura 2000 network in terms of aquatic ecosystem services and water bird biodiversity found in strong modified water bodies as defined by the EU's Water Framework Directive.

Aquatic ecosystems are of the utmost importance to all species and to all ecosystem functions and services. Habitats of particular interest to food and agriculture include artificial aquatic habitats like aquaculture ponds, irrigated land and seasonally flooded agricultural land[54].

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[53] https://www.eumofa.eu/documents/20178/442176/Freshwater+aquaculture+in+the+EU.pdf

[54] J. Bélanger and D. Pilling, Eds. (2019). *The state of the world's biodiversity for food and agriculture*. Rome: FAO Commission on Genetic Resources for Food and Agriculture Assessments. http://www.fao.org/3/CA3129EN/CA3129EN.pdf.

From an ecological point of view, fishponds rely on natural conditions of wetland habitat, and their management aims to artificially strengthen these processes to increase their production. Fishpond production in the European Union is based on common carp with a characteristic age and species composition. Fishponds operate as an open ecological system in which natural and technological processes are in synergy and cannot be separated. This also means that fishpond production is a good example of a circular economy because it relies on the renewal of natural resources. As a result, a fishpond ecosystem is created; beyond the primary production of common carp, it sustains an even greater natural value[55]. As a result of pond farming technology, a specific fishpond ecosystem is created that is closely related to natural wetland habitats. Although this is a human-made system, the nature of its nutrient cycling is identical to natural semi-static wetlands. The fishpond ecosystem is also similar to natural aquatic ecological systems in complexity. The larger patches of homogeneous habitat (e.g., open water, dry pond bottom, reeds) allow specific taxa to be more diverse than in natural habitats; on the whole, however, the biodiversity of fishponds is lower than their natural counterparts. Even so, farming ponds have been highlighted multiple times as regional biodiversity hotspots in recent decades for providing habitats and refuges for some of the most endangered wetland animals[56].

Fig. 9. Diverse habitat types of fishponds are strategic elements in the biodiversity protection of aquatic birds; autumn aspect with low water level, after harvest, Hungary. Photo credit: ©László Csiszár.

[55] Halasi-Kovács, B. (2008) Conservational significance of the Hortobagy Fishfarm, the natural values of the fishponds. Manuscript. (In Hungarian).

Turkowski, K. and A. Lirski. (2011) Non-productive functions of fish ponds and their possible economic evaluation. In Lirski A. and A. Pyć, Eds., *Carp culture in Europe: Current status, problems, perspective*s. Olsztyn, Poland: IRŚ Olsztyn.

[56] Hill, M.J., C. Hassall, B. Oertli, L., Fahrig, B., Robson, J. Biggs, M. Samways, N. Usio, N. Takamura, J. Krishnaswamy and P.J. Wood. (2018). New policy directions for global pond conservation. *Conservation Letters* 11, e12447. https://doi.org/10.1111/conl.12447.

This type of traditional aquaculture is a component of local farming systems and regional social ecosystems and is managed in accordance with farmers' overall strategies for the use of their labour capacity and environment resources. Traditional aquaculture, also called 'integrated aquaculture', uses low trophic level species (carnivorous, plankton feeders) and usually employs a combined stocking formula containing all trophic levels.

Other than their significant values for conservation, these communities have the potential to provide ecosystem services to people[57]. Based on the results of the latest case studies from Hungary, extensive or semi-intensive aquaculture can provide provisioning services including natural fish yield, reed production, feed for grazing livestock and firewood. Regulating and maintaining types of ecosystem services can include microclimate regulation, carbon sequestration and storage, air quality regulation and water quantity and quality regulation. In the case of cultural ecosystem services, traditional aquaculture can provide aesthetic value, cultural heritage and inspirational values, opportunities for scientific research, opportunities for environmental education and recreation[58]. Research studies have indicated other possible ecosystem services related to aquacultures[59].

In terms of quantifying and valuing the contribution of carp pond fish farming to ecosystem services, there are few references, but some results have been published in Central and Eastern Europe. For example, the total value of ecosystem services provided by carp ponds in Poland has been calculated at 52,857 euros/ha[60]. An initial study in Germany reports 16,051 euros/ha annually from ecosystem services delivered by carp ponds.[61] In Czechia, the ecosystem service of nitrogen and phosphorus removal by carp ponds has been calculated at 2,300 euros/ha year[62]. In Hungary, a recent report[63]

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[57] Willot, P.-A., J. Aubin, J.-M., Salles and A. Wilfart. (2019). Ecosystem service framework and typology for an ecosystem approach to aquaculture. *Aquacultures* 512, 734260. https://doi.org/10.1016/j.aquaculture.2019.734260.

[58] Palásti, P., M. Kiss, A. Gulyás and E. Kerepeczki. (2020). Expert knowledge and perceptions about the ecosystem services and natural values of Hungarian fishpond systems. *Water* 12, 2144. https://doi.org/10.3390/w12082144.

[59] Willot, P.-A., J. Aubin, J.-M., Salles and A. Wilfart. (2019). Ecosystem service framework and typology for an ecosystem approach to aquaculture. *Aquacultures* 512, 734260. https://doi.org/10.1016/j.aquaculture.2019.734260.

[60] Turkowski, K. and A. Lirski. (2011) Non-productive functions of fish ponds and their possible economic evaluation. In Lirski A. and A. Pyć, Eds., *Carp culture in Europe: Current status, problems, perspective*s. Olsztyn, Poland: IRŚ Olsztyn.

[61] Seitel, C. and M. Oberle. (2019). Ökosystemdienstleistung der Karpfenteichwirtschaft. *Fischer & Teichwirt* 11, 409–412.

[62] Koushik, R., J. Vrba S. Koushik and J. Mraz. (2020). Nutrient footprint and ecosystem services of carp production in European fishponds in contrast to EU crop and livestock sectors. *Journal of Cleaner Production* 270, 122268. https://doi.org/10.1016/j.jclepro.2020.122268.

[63] Foundation for Development of Fisheries Sciences – NAIK Research Institute for Fisheries and Aquaculture. (2020). Role of freshwater pond aquaculture in the maintenance of natural values of wetland habitats. Szarvas. https://www.sciencedirect.com/science/article/pii/S0959652620323155

analysing *inter alia* the economic assessment of natural values and ecosystem services of fishponds highlights the complexity of evaluating different ecosystem services and the need for an interdisciplinary approach to determine hypothetical but nevertheless plausible values for these services that is not related to a financial support scheme.

The use of ecosystem services provides a strong basis for the development of sustainable, multifunctional fish farms. The main advantage of these systems over traditional ones is that, in addition to fish sales, revenues from other services, whether provisioning or cultural, can also be obtained, which at least partly compensates for losses or additional costs due to the direct or indirect impacts of maintaining biodiversity on the farms (such as damage to fish stocks by protected fish-eating bird species like *Phalacrocorax carbo)*[64]. 'Feeding' ichthyophagous birds and mammals at the fish farmer's expense is not a part of the accounting system and cannot be reported to the tax authorities.

4.3. Estuarine and lagoon aquaculture ecosystem services

Lagoons are under constant pressure generated by human activities and are one of the most threatened ecosystems in the world. Most of the impact comes from outside the aquaculture sector in the form of pollution, agricultural fertilizers being discharged into lagoons, urban-discharged effluents, industrial pollution with heavy metals and PCBs and the overprotection of piscivorous birds, leading to an alteration of the biogeochemical balances that allow the lagoon ecosystem to function.

Some of the effects that aquaculture has on the ecological status of lagoons have been addressed, while others have gained farmers' and researchers' attention. The overall contribution of the aquaculture of all lagoon types to ecosystems is positive; even the fact that traditional aquaculture has thrived for hundreds of years in these ecosystems is evidence of the need for a better and more supportive policy. The maintenance of substantial ecological stability is the basis of the long-term profitability of a lagoon aquaculture farm. Coastal lagoons would not have lasted without ongoing management by local communities (fish farmers and fishers) aimed at enhancing fish production or hunting, thus enabling not only the physical conservation of these environments but also the maintenance of their biodiversity value. In fact, human activities that mimic natural processes and dynamics, as described in this recommendation, allow not only ecological communities but also economic activities to survive.

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[64] Bozánné Békefi, E., G. Gyalog and L. Váradi. (2017). A multifunkcionális halgazdaságok szerepe és jelentősége. *Jelenkori társadalmi és gazdasági folyamatok* 12 (1–2), 121–125. https://doi.org/10.14232/jtgf.2017.1-2.121-125.

Fig. 11. Coastal lagoons in the Bay of Cadiz (Spain). Photo credit: ©J.C. Macias, 2011.

As for other types of aquaculture, the ecosystem services assessment for all forms of lagoon aquaculture has identified several contributions: food provisioning (fish and shellfish), freshwater storage, hydrological balance, water purification, climate regulation, flood protection, oxygen production, fertility, recreation and ecotourism. 'The conservation of the lagoons is therefore relevant for their ecological importance, along with the valuable ecosystem services they provide for human welfare'.[65]

The other two steps for a holistic approach to ecosystem services for not only lagoons but also other types of aquaculture, quantifying and valuing, are still awaiting standardization as a result of a joint scientific effort by farmers, economists, ecologists and environmental scientists. The available data show, for example, that the ecosystem cultural services provided by the Venice lagoon are estimated at 530 million euros annually, or 12 million euros/km^2, but there is little research on the specific contribution of aquaculture to this result.

5. Conclusions

The cultivation of bivalve molluscs and extensive and semi-intensive fish farming in ponds and estuaries are activities with a long history in Europe and provide quality and healthy foods that are part of the rich gastronomy of the EU.

These types of aquaculture contribute to the food security and the well-being of rural and coastal communities in many regions of the EU by generating wealth and employment.

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[65] Newton, A., A. Brito, J. Icely, V. Derolez, I. Clara, S. Angus, G. Schernewski, M.Inácio, A. Lillebø, A. Sousa, B. Béjaoui, C. Solidoro, M. Tosic, M. Cañedo-Argülles, M. Yamamuro, S. Reizopoulou, H.-C. Tseng, D. Canu, L. Roselli, M. Maanan, S. Cristina, A. Ruiz-Fernández, R. de Lima, B. Kjerfve, N. Rubio-Cisneros, A. Pérez-Ruzafa, C. Marcos, R. Pastres, F. Pranovi, M. Snoussi, J. Turpie, Y. Tuchkovenko, B. Dyack, J. Brookes, R. Povilanskas and V. Khokolov. (2018). Assessing, quantifying and valuing the ecosystem services of coastal lagoons. *Journal of Natural Conservation* 44, 50–65. https://doi.org/10.1016/j.jnc.2018.02.009.

Well-managed finfish in ponds, lagoons and estuaries and bivalve aquaculture contribute significantly to the preservation and improvement of environment, maintain the biodiversity associated with aquatic ecosystems and generate ecosystem services to society that are not always recognized.

The specifics of these aquacultures in terms of both ecosystem services and needs should be better understood and acknowledged by policy makers and the public.

6. Recommendations

6.1. Recommendations for shellfish farming

6.1.1. Measures to be included in National Aquaculture Plans

1) Aquaculture ecosystems derived from the extensive farming of bivalve molluscs (shellfish farming ecosystems) must be identified and recognized as part of the natural heritage linked to human productive activities;

2) Shellfish waters must be effectively protected, as they are especially sensitive to loss of water quality;

3) Coherence between the water register for shellfish farming and its protection, in accordance with the EU's Water Framework Directive and appropriate regulation and support for the ecosystem services of shellfish farming, in line with the EU biodiversity strategy, should be promoted;

4) The ecosystem services that shellfish farming provides must be studied, evaluated and emphasized by financing research on ecosystem services provided by these aqua-ecosystems;

5) The products of shellfish farming, its details and its history and traditions should be promoted by marketing activities and campaigns (in line with the Farm to Fork strategy);

6) The people – shellfish farmers – who maintain and conserve these aqua-ecosystems and their services must be explicitly recognized and supported;

7) To reinforce the social structure of the shellfish production sector, the representative structures of the sector should be protected by the entities that manage the official EU signs of quality (PDO, PGI, TSG);

8) The incorporation of young people into extensive shellfish farming activities should be facilitated and promoted;

9) Actions should be supported to increase public awareness in support of sustainable aquaculture of bivalve molluscs as food production systems that generate ecosystem services, have a low carbon footprint and enrich biodiversity;

10) The consumption of natural and healthy animal proteins produced by extensive shellfish aquaculture should be promoted, especially among children and young people (in line with the Farm to Fork strategy).

6.1.2. Measures for the European Commission

1) Recognize and adequately support the role in and importance for society of shellfish farming, with its local knowledge and long-standing traditions and ecosystem services;

2) Rationalize the administrative procedures involved with shellfish farming;

3) Collect science-based knowledge about the natural values and ecosystem services of shellfish aquaculture;

4) Follow the AAC recommendation on the development of shellfish-specific guidelines (June 2020 – AAC 2020–05) and the AAC Recommendation 'Protecting the Quality of Shellfish Water' (October 2019);

5) Take into consideration the positive aspects generated by mollusc farming waters in the fight against coastal eutrophication and climate change, in order to formulate and support actions in the development of European policies for the Green Deal and protection of biodiversity;

6) Develop knowledge platforms containing research results regarding shellfish aquaculture ecosystem services and their natural value;

7) Promote a broad program of dissemination of these results to facilitate their knowledge among society;

8) Support the maintenance of and strengthen the ecosystem services of shellfish aquaculture;

9) Determine the production losses caused by special protected species in bivalve farms and establish support and compensation mechanisms for producers.

6.2. Recommendations for pond, lagoon and estuary finfish aquaculture

6.2.1. Measures to be included in National Aquaculture Plans

1) Provide appropriate regulation and support for ecosystem services of pond, lagoon and estuary fish farming (in line with the EU biodiversity strategy);
2) Put in place coordinated spatial planning for waters and land and secure adequate allocation of space for aquaculture to provide ecosystem services and simplify bureaucratic procedures in both access to space and licensing to ensure the long-term existence of this kind of aquaculture;
3) Provide specific support to maintain the functionality of pond, lagoon and estuary farms to preserve wetland;
4) Provide specific support for recoupling short rural-urban food webs and local markets to sustain biodiversity at the local level;
5) Finance research on ecosystem services provided by pond, lagoon and estuary fish farming;
6) Promote the products of fishpond farming, its characteristics and the role of polyculture through marketing activities and campaigns (in line with the Farm to Fork strategy);
7) Support educational programmes in extensive and semi-intensive aquaculture activities to avoid their unattractiveness to and abandonment by young farmers;
8) Develop knowledge platforms containing research results regarding aquaculture ecosystem services;
9) Implement effective fish predator management plans for otters, cormorants, herons and so on.

6.2.2. Measures for the European Commission

1) Recognize and adequately support the role in and importance for society of shellfish farming, with its local knowledge and long-standing traditions and ecosystem services;
2) Present an overview of the application of article 54 (R508/2014) in the Member States;
3) Reduce administrative procedures for this type of fish farming and for other systems with a positive effect on the environment, such as shellfish and algae;
4) Collect science-based knowledge about the natural value and ecosystem services of finfish aquaculture, especially traditional European pond and lagoon aquaculture;
5) Consider the positive aspects of water areas provided by these farming systems in order to

formulate policy papers with actions against climate change (in line with, for example, the Green Deal);

6) Evaluate the contribution and impact of the guidelines issued on the Water Framework Directive and N2000 directives at the national level.

7) Although the value of the ecosystem services provided by pond, lagoon and estuary farming is significantly greater than that of any agricultural sector, support for the complex natural value services created and maintained by aquaculture is significantly lower than for agriculture. We stress the importance of resolving this contradiction by focusing on the objectives of the EU Green Deal. It is necessary to acknowledge the values of aquaculture as at least the same level as agriculture and increase support for them, as in agriculture;

8) Develop knowledge platforms containing research results regarding aquaculture ecosystem services;

9) Evaluate the protection status of special protected species causing fish losses in ponds;

10) Investigate the possibility of increasing the sharing of the circular economy in pond, lagoon and estuary aquaculture;

11) Disseminate the natural values and ecosystem services of pond, lagoon and estuary aquaculture sites and their role in the maintenance of wetland habitats;

12) Develop educational programmes to raise awareness, knowledge and understanding of aquaculture, focusing on pond, lagoon and estuary aquaculture, focus on their natural values and ecosystem services;

13) Support the maintenance of and strengthen the ecosystem services of pond, lagoon and estuary aquaculture;

14) To maintain the natural values and ecosystem services of pond, lagoon and estuary aquaculture, it is necessary to work out a compensation mechanism for damage caused by wildlife connected to fishpond and lagoon habitats.

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