Recommendation - Shellfish farming as a nitrogen sink

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Contents

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1. Context

Excess nitrogen induces pollution much less known than that caused by carbon, but this pollution is just as dangerous for the environment and health (eutrophication, groundwater unfit for consumption, acidification of land and lakes, respiratory and cardiovascular diseases, etc.) [1]. This damage, mainly due to agriculture, is estimated at between EUR 70 and 320 billion each year in the European Union, or EUR 150 to 740 per person per year, more than double the benefits of using nitrogen for European agriculture. These are the figures published by the first European Nitrogen Assessment (ENA) [2], published on 18 April 2011 at the international conference on Nitrogen and Climate Change in Edinburgh (Scotland), after five years of work by researchers from all over Europe.

The Haber-Bosch process, the scientific innovation that made possible, in 1908, the industrial production of ammonia and therefore the production of artificial nitrogen fertilizers, revolutionized agriculture, by multiplying yields, and made it possible to feed a growing population. This process produces ammonia (NH3) from atmospheric nitrogen and a large amount of energy in the form of natural gas [1]. However, because of this discovery, nitrogen emission into the environment has doubled worldwide, and more than three times in Europe, becoming a threat to humanity [12] According to a Dutch study by Ester van der Voet [3], agriculture is responsible for 57% of acid nitrogen rain and 90% of nitrates in groundwater. For coastal nitrate pollution, however, a large share is attributed to domestic wastewater [1].

The main problem is not nitrogen per se, but the fact that it is released into the environment in significant quantities, mainly due to the use of fertilizers in agriculture, the combustion of fossil fuels in industry, for electricity generation, heating, and heavy car traffic in urban areas [1]. Half of the nitrogen used is released in the form of ammonia and nitrates, threatening health, and the environment [12]

On the health side, this 2011 study (ENA) [2] estimates that more than 10 million Europeans are exposed to nitrate levels in water exceeding regulatory thresholds, with an increased risk of cancer if they drink it regularly without it being properly treated. Nitrogen pollution of the air also leads to the formation of particles that cause respiratory diseases and can reduce life expectancy by several months. It would thus be responsible for the premature death of 378,000 people in Europe according to the European Environment Agency in 2018 [13].

2. Justification

A European report, published by the European Commission in May 2018 and covering the period 2012-2015 [4], reports mixed results with a slight improvement in the quantities of nitrogen found in water bodies, particularly groundwater. However, surface waters are improving even more slowly due to uneven efforts by the Member States of the Union. Sensitive areas, designated as vulnerable to nitrates, are on the rise and 61% of the European agricultural area is thus affected by the obligations for sensitive areas. The report does not analyse in depth the situation of transitional waters and coastal waters, which constitute the last receptacle compartment of this pollution. Indeed, only 8 Member States reported data on their transitional waters and 9 did so for their coastal waters. Of these, only 3 are important producers of farmed and fishery molluscs (Ireland, Italy, and Spain). The

France did not release any information. Of these nine reports, five unfortunately reported more than 50% of eutrophic or hypertrophic coastal waters.[1]

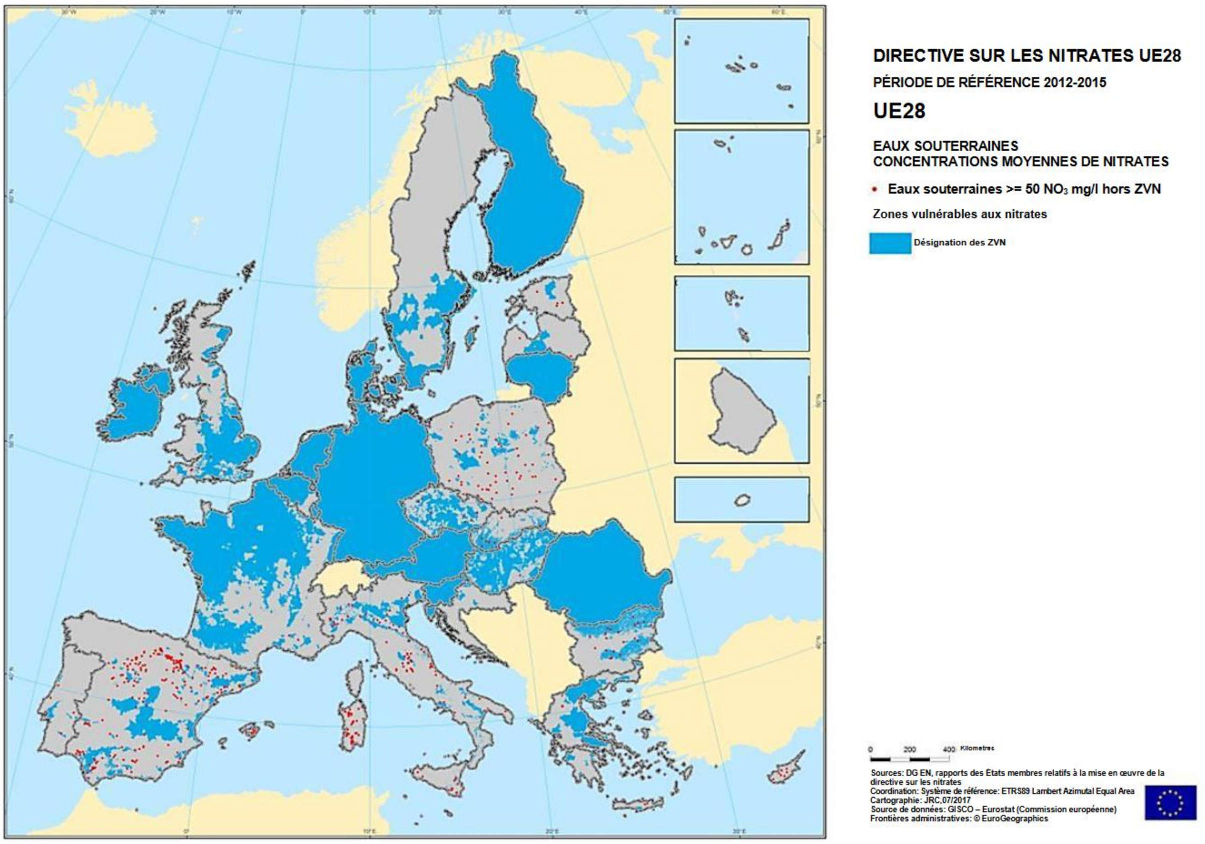

Figure 1. Area designated as nitrate vulnerable and groundwater monitoring stations with average nitrate concentrations above 50 mg/l outside nitrate vulnerable zones, 2012-2015 [4]

In this coastal compartment, excess nitrogen is spectacularly reflected in the phenomena of green algae and biologically dead marine areas that spread along the Brittany coast, in the North Sea, the Adriatic and the Baltic [14]. N deposition in forests has also led to a loss of biodiversity of more than 10% over two-thirds of Europe [15].

"Nitrogen is one of the greatest environmental challenges of the twenty-first century," concluded Mark Sutton, a researcher at the Edinburgh Centre for Ecology, in 2011. In an article in the journal Nature [5], entitled *A good element in too large quantities*, the researcher specifies: *"Excess nitrogen threatens the quality of air, water and land. It affects ecosystems and biodiversity and alters the balance of greenhouse gases."*

In France, the journal of the environment published on April 30, 2019, an alarming report entitled "The green tide season is already open" [6], seeming to indicate that, despite certain preventive aspects

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[1] Said of a body of water (pond, lake, etc.) whose waters enriched with organic matter are the seat of a plant and bacterial proliferation leading to a pronounced deoxygenation of the water (Larousse dictionary).

put in place, including the plans to combat green algae (PLAV), the scourge announced for a decade is growing and this, earlier and earlier.

All these negative impacts entail costs, whether in terms of health care or water treatment and purification, or, although difficult to quantify, losses related to the degradation of ecosystems and the increase in greenhouse gas emissions.

Thus, we must be aware of the need to reduce excess nitrogen emissions into the environment. This reduction mainly involves changes in agricultural practices (implementation of composting and biological treatment systems, reduction in the use of nitrogen fertilizers and intensive livestock farming) [1,5] but also through changes in our lifestyles: favouring low-polluting transport and reducing our consumption of animal proteins in reality, Today, 80% of the nitrogen used in agriculture is used to produce feed for livestock [2].

The treatment by depuration plants is the way Member-States and local authorities use to fight the contamination of water. An excess depuration can leave to an excellent level of N level but a poor level of nutrients in the sea waters [18]. In such a case bivalve molluscs cannot grow correctly.

Bivalve molluscs, a veritable "nitrogen sink", part of the solution

Numerous global scientific studies, a synthesis of which has been made in the framework of "Millennium Ecosystem Assessment" [7], and more specifically at European level an ECASA research and development programme for sustainable aquaculture, have highlighted and quantified the nitrogen sink represented by bivalve molluscs in our European waters, whether wild and fished or farmed.

Tools developed as part of this ECASA program, and more particularly the FARM model, [2]enabled a group of scientists to publish in 2009 in the journal Aquaculture (n°292) an article entitled "Analysis of *coastal and offshore aquaculture: Application of the FARM model to multiple systems and shellfish species*" [8]. This publication concludes that European bivalve molluscs, farmed and fished, represent a nitrogen sink of 57,000 T annually, the equivalent produced and discharged into water by a population of 17 million people (the Dutch population). The equivalent annual operating cost in terms of wastewater treatment plants has been estimated at between €3 billion and €7 billion.

The study lead by Ruth Carmichael in 2011 [19] shows the various remediation of N by the main commercial species:

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[2] http://www.farmscale.org/

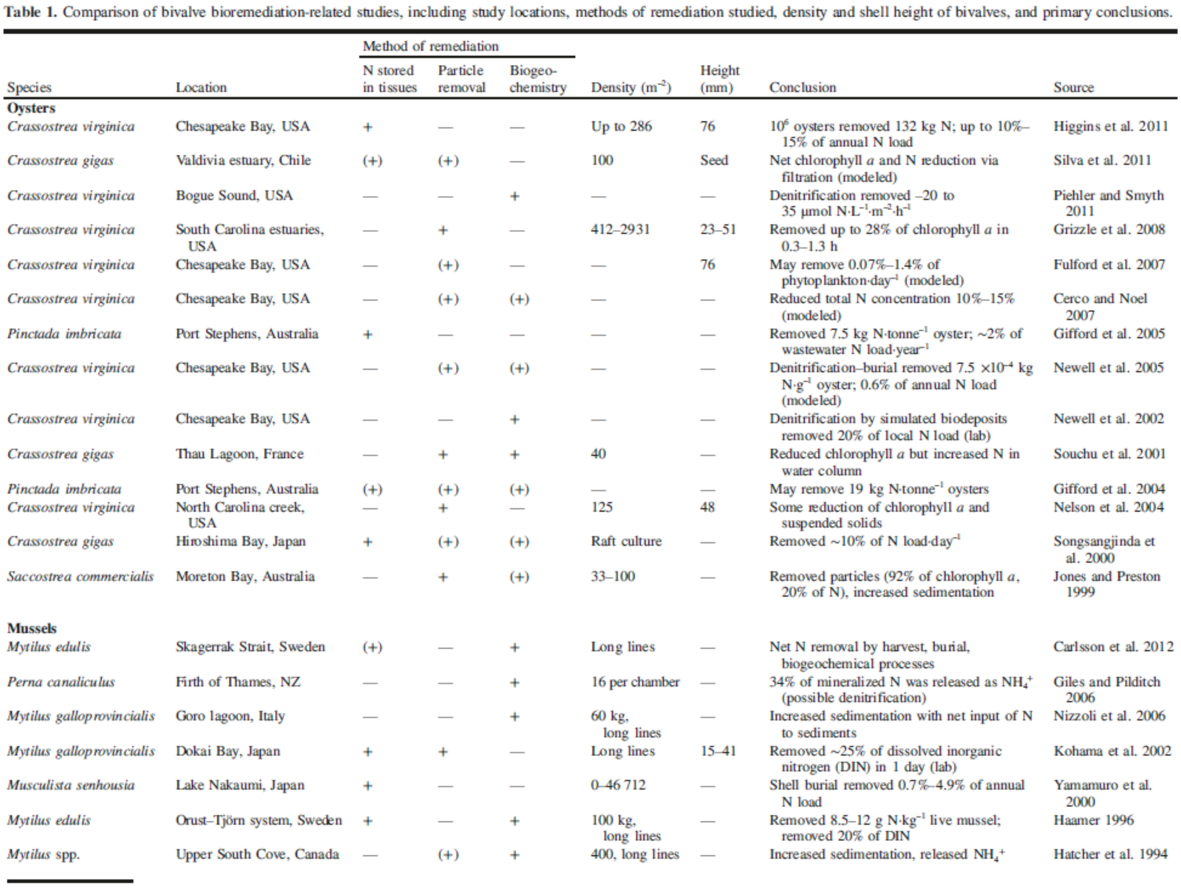


Table 1. Comparison of bivalve bioremediation-related studies, including study locations, methods of remediation studied, density and shell height of bivalves, and primary conclusions.

		Method of remediation						
Species	Location	N stored in tissues	Particle removal	Biogeo-chemistry	Density (m^{-2})	Height (mm)	Conclusion	Source
Oysters								
Crassostrea virginica	Chesapeake Bay, USA	+	—	—	Up to 286	76	10^6 oysters removed 132 kg N; up to 10%–15% of annual N load	Higgins et al. 2011
Crassostrea gigas	Valdivia estuary, Chile	(+)	(+)	—	100	Seed	Net chlorophyll *a* and N reduction via filtration (modeled)	Silva et al. 2011
Crassostrea virginica	Bogue Sound, USA	—	—	+	—	—	Denitrification removed –20 to 35 μmol $N \cdot L^{-1} \cdot m^{-2} \cdot h^{-1}$	Piehler and Smyth 2011
Crassostrea virginica	South Carolina estuaries, USA	—	+	—	412–2931	23–51	Removed up to 28% of chlorophyll *a* in 0.3–1.3 h	Grizzle et al. 2008
Crassostrea virginica	Chesapeake Bay, USA	—	(+)	—	—	76	May remove 0.07%–1.4% of phytoplankton$\cdot day^{-1}$ (modeled)	Fulford et al. 2007
Crassostrea virginica	Chesapeake Bay, USA	—	(+)	(+)	—	—	Reduced total N concentration 10%–15% (modeled)	Cerco and Noel 2007
Pinctada imbricata	Port Stephens, Australia	+	—	—	—	—	Removed 7.5 kg $N \cdot tonne^{-1}$ oyster; ~2% of wastewater N $load \cdot year^{-1}$	Gifford et al. 2005
Crassostrea virginica	Chesapeake Bay, USA	—	(+)	(+)	—	—	Denitrification–burial removed 7.5 $\times 10^{-4}$ kg $N \cdot g^{-1}$ oyster; 0.6% of annual N load (modeled)	Newell et al. 2005
Crassostrea virginica	Chesapeake Bay, USA	—	—	+	—	—	Denitrification by simulated biodeposits removed 20% of local N load (lab)	Newell et al. 2002
Crassostrea gigas	Thau Lagoon, France	—	+	+	40	—	Reduced chlorophyll *a* but increased N in water column	Souchu et al. 2001
Pinctada imbricata	Port Stephens, Australia	(+)	(+)	(+)	—	—	May remove 19 kg $N \cdot tonne^{-1}$ oysters	Gifford et al. 2004
Crassostrea virginica	North Carolina creek, USA	—	+	—	125	48	Some reduction of chlorophyll *a* and suspended solids	Nelson et al. 2004
Crassostrea gigas	Hiroshima Bay, Japan	+	(+)	(+)	Raft culture	—	Removed ~10% of N $load \cdot day^{-1}$	Songsangjinda et al. 2000
Saccostrea commercialis	Moreton Bay, Australia	—	+	(+)	33–100	—	Removed particles (92% of chlorophyll *a*, 20% of N), increased sedimentation	Jones and Preston 1999
Mussels								
Mytilus edulis	Skagerrak Strait, Sweden	(+)	—	+	Long lines	—	Net N removal by harvest, burial, biogeochemical processes	Carlsson et al. 2012
Perna canaliculus	Firth of Thames, NZ	—	—	+	16 per chamber	—	34% of mineralized N was released as NH_4^+ (possible denitrification)	Giles and Pilditch 2006
Mytilus galloprovincialis	Goro lagoon, Italy	—	—	+	60 kg, long lines	—	Increased sedimentation with net input of N to sediments	Nizzoli et al. 2006
Mytilus galloprovincialis	Dokai Bay, Japan	+	+	—	Long lines	15–41	Removed ~25% of dissolved inorganic nitrogen (DIN) in 1 day (lab)	Kohama et al. 2002
Musculista senhousia	Lake Nakaumi, Japan	+	—	—	0–46 712	—	Shell burial removed 0.7%–4.9% of annual N load	Yamamuro et al. 2000
Mytilus edulis	Orust–Tjörn system, Sweden	+	—	+	100 kg, long lines	—	Removed 8.5–12 g $N \cdot kg^{-1}$ live mussel; removed 20% of DIN	Haamer 1996
Mytilus spp.	Upper South Cove, Canada	—	(+)	+	400, long lines	—	Increased sedimentation, released NH_4^+	Hatcher et al. 1994

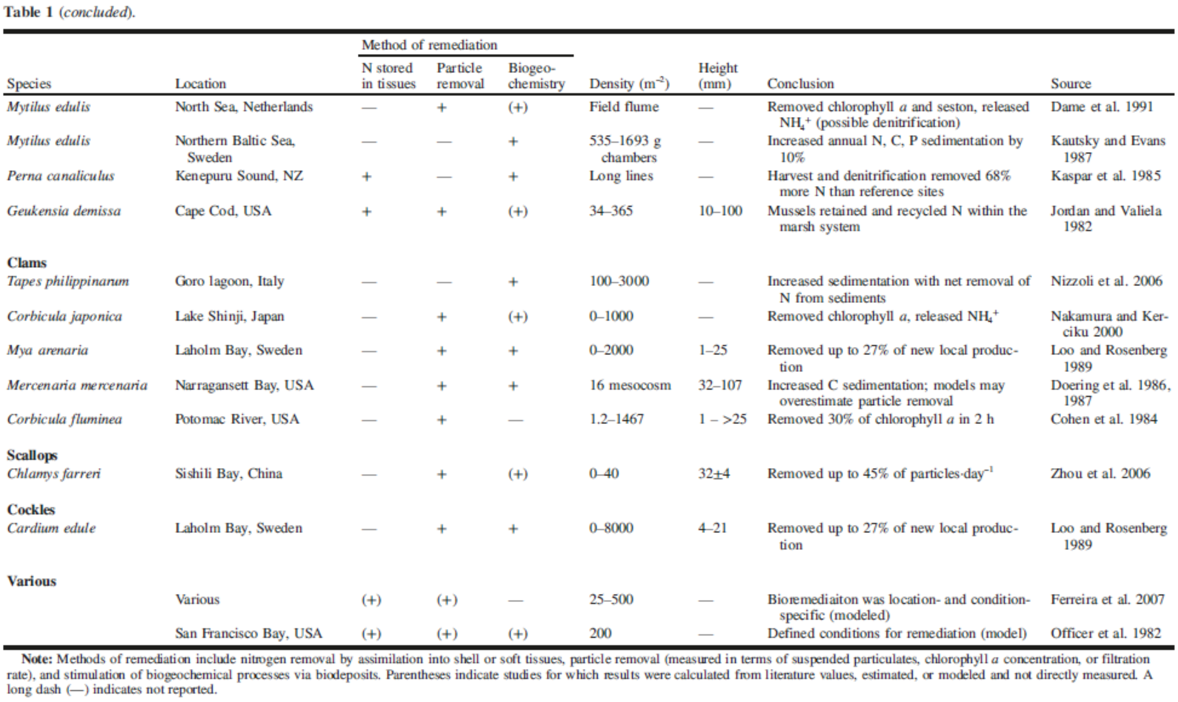


Table 1 (*concluded*).

		Method of remediation						
Species	Location	N stored in tissues	Particle removal	Biogeo-chemistry	Density (m^{-2})	Height (mm)	Conclusion	Source
Mytilus edulis	North Sea, Netherlands	—	+	(+)	Field flume	—	Removed chlorophyll *a* and seston, released NH_4^+ (possible denitrification)	Dame et al. 1991
Mytilus edulis	Northern Baltic Sea, Sweden	—	—	+	535–1693 g chambers	—	Increased annual N, C, P sedimentation by 10%	Kautsky and Evans 1987
Perna canaliculus	Kenepuru Sound, NZ	+	—	+	Long lines	—	Harvest and denitrification removed 68% more N than reference sites	Kaspar et al. 1985
Geukensia demissa	Cape Cod, USA	+	+	(+)	34–365	10–100	Mussels retained and recycled N within the marsh system	Jordan and Valiela 1982
Clams								
Tapes philippinarum	Goro lagoon, Italy	—	—	+	100–3000	—	Increased sedimentation with net removal of N from sediments	Nizzoli et al. 2006
Corbicula japonica	Lake Shinji, Japan	—	+	(+)	0–1000	—	Removed chlorophyll *a*, released NH_4^+	Nakamura and Kerciku 2000
Mya arenaria	Laholm Bay, Sweden	—	+	+	0–2000	1–25	Removed up to 27% of new local production	Loo and Rosenberg 1989
Mercenaria mercenaria	Narragansett Bay, USA	—	+	+	16 mesocosm	32–107	Increased C sedimentation; models may overestimate particle removal	Doering et al. 1986, 1987
Corbicula fluminea	Potomac River, USA	—	+	—	1.2–1467	1 – >25	Removed 30% of chlorophyll *a* in 2 h	Cohen et al. 1984
Scallops								
Chlamys farreri	Sishili Bay, China	—	+	(+)	0–40	32±4	Removed up to 45% of $particles \cdot day^{-1}$	Zhou et al. 2006
Cockles								
Cardium edule	Laholm Bay, Sweden	—	+	+	0–8000	4–21	Removed up to 27% of new local production	Loo and Rosenberg 1989
Various								
	Various	(+)	(+)	—	25–500	—	Bioremediaiton was location- and condition-specific (modeled)	Ferreira et al. 2007
	San Francisco Bay, USA	(+)	(+)	(+)	200	—	Defined conditions for remediation (model)	Officer et al. 1982

Note: Methods of remediation include nitrogen removal by assimilation into shell or soft tissues, particle removal (measured in terms of suspended particulates, chlorophyll *a* concentration, or filtration rate), and stimulation of biogeochemical processes via biodeposits. Parentheses indicate studies for which results were calculated from literature values, estimated, or modeled and not directly measured. A long dash (—) indicates not reported.

A recent study, published in November 2018, entitled "Global review of ecosystem services provided by bivalve aquaculture" [9] lists all the ecosystem services provided by molluscs (shells being a source of limestone for soil fertilization, bioremediation and filtration actions, location of farms reducing coastal erosion, etc.). and quantifies, for livestock services, the value of these services, valued globally at $23.9 billion.

Point of view of MSC certifying Sweden:

Mussel farms are regarded by the County Administrative Board (Länsstyrelsen i Västra Götalands Län) as 'low risk' with regards to habitat and the environment: The impact/effects from mussels are regarded as small and mostly positive with regards to eutrophication.

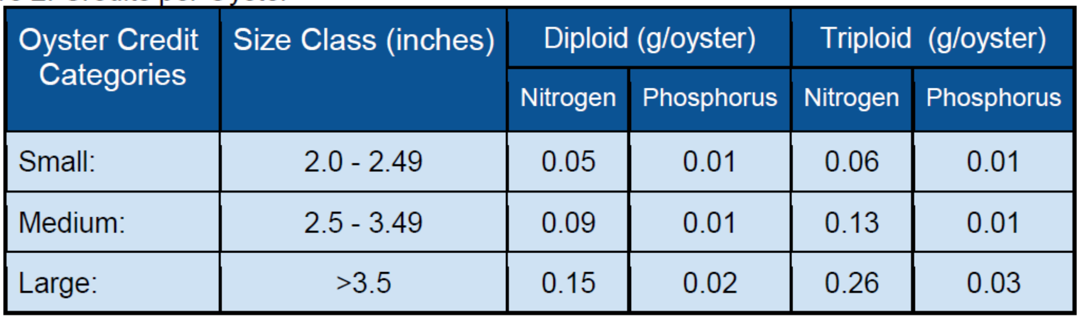
The levels of eutrophication are high in both the Skagerrak/Kattegat and the Baltic. Mussel farming is seen as a way of reducing the level of eutrophication and improving the water quality. In such a frame, the University of Gothenburg is involved in the BONUS-Optimus project (an EU-program with focus on the Baltic Sea), in which all Baltic countries are involved. Within BONUS-Optimus, there is a project together with German, Polish, Swedish, and Danish partners, to look at growing conditions for blue mussels and mussel growth to combat eutrophication [16] [17].

Point of view of MSC Denmark:

The MSC rapport "Limfjord hangcultuur" points that the MUMIHUS project (2010-2014) tested the use of nutrient extraction cultures as a combination of biological production and a tool for mitigating effects of eutrophication in Danish coastal areas using blue mussels (Mytilus edulis) as the culture organism. The results showed that it was possible to obtain a high area specific biomass of 60 t-WW/ha, which is equivalent to a nitrogen and phosphorus removal of 0.6–0.9 and 0.03–0.04 t ha/yr., respectively, making mitigation by mussel production a cost-efficient measure compared to the most expensive land-based measures (Petersen et al. 2014). The farms had a positive effect on the ecosystem through the filtering of phytoplankton and suspended matter, which were reduced on average by 13-30% and >50% within the farm area (Nielsen et al. 2016). The last assessment of 2022 can be extracted from MSC internet site

Dvarkas et al. analysed in 2020 the N removal service provided by shellfish aquaculture at the level of a sub watershed [20]. This kind of research made it possible to the Maryland government is the USA to provide a payment system for this N and P remediation services like the table below shows.

Figure 2. Credits per Oyster



Oyster Credit Categories	Size Class (inches)	Diploid (g/oyster)		Triploid (g/oyster)	
		Nitrogen	Phosphorus	Nitrogen	Phosphorus
Small:	2.0 - 2.49	0.05	0.01	0.06	0.01
Medium:	2.5 - 3.49	0.09	0.01	0.13	0.01
Large:	>3.5	0.15	0.02	0.26	0.03

3. Recommendations

- AAC recommends recognizing and qualifying the N services provides by shellfish and to include a sentence in the EU law on restauration of Nature, and the law on the sustainable food system, or the secondary regulations based on these main laws.
- AAC recommends that the Commission ask its Unit of Scientific Advice Mechanism to define an EU algorithm to quantify the N service provided by bivalve molluscs.
- AAC recommends finally that Commission investigate the regulatory way to setup an independent system of certification of this N service provided by bivalve mollusc at the level of the EU sub watershed level as defined in the Water Framework Directive, and the corresponding payment to the farmers.

Bibliography

[1]. Schneider F. (2008). Decay of Haber-Bosch processes

[2]. European Scientific Consortium (2011). European Nitrogen Assessment (ENA), http://www.nine-esf.org/node/360/ENA-Book.html

[3]. Ester van der Voet (1996). Nitrogen pollution in the European Union, chapter 8, In: PhD thesis, Substances from cradle to grave: CML, Leiden, The Netherlands

[4]. European Commission (2018). Report from the Commission to the Council and the European Parliament on the implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources, based on Member States' reports for the period 2012-2015, https://ec.europa.eu/transparency/regdoc/rep/1/2018/FR/COM-2018-257-F1-FR-MAIN-PART-1.PDF

[5]. Suton M.A., Oenema O., Erisman J.W. et al (2011). Too much for a good thing, Nature international journal of sciences, 471, 159-161 [online] (accessed 31/03/2015), https://www.nature.com/articles/472159a

[6]. Senet S. (2019). The green tide season has already begun, Le journal de l'environnement [online] (accessed 03/07/19), http://www.journaldelenvironnement.net/article/la-saison-des-marees-vertes-est-deja-ouverte,97372

[7]. Reid W.V., Mooney H.A., Cropper A. et al (2005). Millennium Ecosystem Assessment Synthesis Report http://www.millenniumassessment.org/documents/document.447.aspx.pdf

[8]. Ferreira J.G., Sequeira A., Hawkins A.J.S. et al (2009). Analysis of coastal and offshore aquaculture: Application of the FARM model to multiple systems and shellfish species

[9]. Van der Schatte Olivier A., Jones L., Le Vay L. et al (2018). A global review of the ecosystem services provided by bivalve aquaculture

[10]. Chevassus-au-Louis B. and Andaral B. (2012). CGAAER, CGEDD, Review of scientific knowledge on the causes of green macroalgae blooms, Application to the situation of Brittany and proposals

[11]. Nitrogen fertilizer prices http://www.revenuagricole.fr/focus-marches/cerealier/focus-produits/engrais/engrais-2/23669-le-marche-international-continue-d-exercer-une-pression-baissiere

[12]. Ashoka Mukpo (2021), Nitrogen: The Environmental CrisisYou Have Not Heard of Yet, UP-Magazine https://up-magazine.info/planete/climat/93757-azote-la-crise-environnementale-dont-vous-navez-pas-encore-entendu-parler/

[13] European Environment Agency Air Quality Report 2020

[14] Green algae invade the Baltic Sea (2018) Maxiscience

[15] Didier Alard (2019) Feeding the planet without standardizing it: the dangers of nitrogen pollution, Foundation for Research on Biodiversity

[16] Karen Timmerman et al. (2019) Mussel production as a nutrient mitigation tool for improving marine water quality

[17] Jonne Kotta et al. (2020) Cleaning up seas using blue growth initiatives: Mussel farming for eutrophication control in the BalticSea

[18] Matteo Fanelli et al; (2022) Impact of depuration plants on nutrient levels in the North Adriatic Sea

[19] Ruth H. Carmichael, William Walton, and Heidi Clark (2012) Bivalve-enhanced nitrogen removal from coastal estuaries

[20] Anthony Dvarskas et al. (2020) Quantification and valuation of Nitrogen removal services provided by shellfish aquaculture at the subwatersheds scale

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