Environmental impacts of producing bouchot mussels in Mont-Saint-Michel Bay (France) using LCA with emphasis on potential climate change and eutrophication

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ABSTRACT

LCA of bouchot blue mussel culture in Mont Saint-Michel Bay (France) was performed to identify impact hotspots of the activity. To better characterize potential positive effects on eutrophication and climate change, the chemical composition of the flesh and shell was analyzed. A small but potential mitigating effect on eutrophication was observed, reaching 1 kg PO_4-eq. per tonne of "ready-to-cook" mussels. The potential carbon sink effect is influenced by hypotheses about the wooden stakes of the bouchots and about the fate of the shells, associated to the management of discarded mussel and of the household waste. This effect barely compensates the climate change due to the use of fuel for on-site transportation. In addition, environmental impacts of blue mussel culture depend on its production location, as a function of mussel yields due to the marine currents combined with the distance to on-shore infrastructure.

Keywords: LCA, Mussel, Carbon sink, Eutrophication, Climate change

1. Introduction

Blue mussel (*Mytilus edulis*) culture yielded 207,918 tonnes of shellfish worldwide in 2010 (FAO 2012). Blue mussel culture in France represents about 35% of world production (CNC 2012) and is performed using two different techniques: long-line rafts and bouchots. Bouchot culture is currently the only type of mussel culture in Mont Saint-Michel Bay, which produces 10,000 tonnes of blue mussels annually. Bouchot culture consists of using wooden stakes sunk into the foreshore as a culture support for the mussels.

In the scientific literature, interactions between mussel culture and the environment have been studied mainly from a nutrient-cycling perspective (Brigolin et al. 2009, Jansen 2012, Nizzoli et al. 2011, Richard et al. 2006) or one assessing biodeposition and benthic effects (Chamberlain et al. 2000, Christenssen et al. 2003, Grant et al. 2012). Few authors have assessed environmental impacts of mussel culture with a broader viewpoint using holistic approaches. Thrane (2004) assessed energy consumption of mussel production in Denmark, Fry (2012) estimated a carbon footprint of longline mussel production in Scotland, and Iribarren et al. (2010a,b,c) performed Life Cycle Assessment (LCA) of the longline mussel supply chain in Spain. Among these studies, the methodology used to establish an inventory differs and the inclusion of effects of mussels on nutrient and carbon cycling in the marine environment varies.

Mont Saint-Michel Bay is located between Brittany and Normandy, two regions of high livestock production, where water quality is regularly called into question due to overloading of nitrogen (N) and phosphorus (P) caused by agricultural activities. Our study aimed to evaluate environmental impacts of bouchot mussel production in this context. In particular, we investigated its potential role in mitigating climate change by stocking carbon in mussel shells and potential eutrophication by extracting nutrients from the bay.

2. Methods

2.1. Goal and scope

LCA was performed to assess environmental impacts of Mont Saint-Michel mussels produced according to the Appellation d'Origine Contrôlée (AOC) label, with the double objective of establishing an environmental profile of the activity and highlighting potential impact hotspots. The LCA followed the main guidelines of the ILCD handbook (JRC 2011), with a cradle-to-gate approach. Boundaries of the production system included spat collection and transportation, the culture stage (including equipment use), and the processing and packaging stage at the producer organization's plant (Fig. 1). The distribution, marketing and consumption stages are not included in the study. The functional unit was 1 tonne of packed, “ready-to-cook” mussels at the producers’ plant.

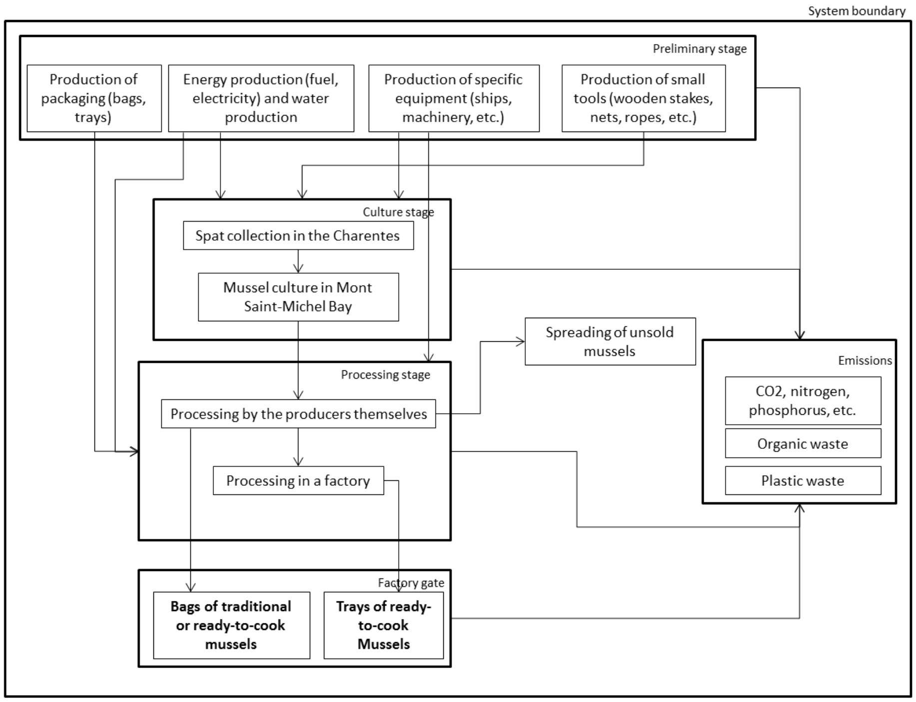

Figure 1. Stages of the mussel-production system included in the LCA

2.2. Life cycle inventory

Six of the main producers, operating in two or three subareas of the bay (Center, East, Far East), were interviewed from spring to summer 2012. They produced 300-450 tonnes of mussels per year. Their practices are regulated according to AOC specifications, which restrict the percentage of bouchots in use at the same time (55-65% according to the area) and the maximum mean annual yield to 60 kg of mussels per bouchot. These rules aim to preserve the productivity of the bay, and some producers have chosen to use only 50% of their bouchots at the same time. Bouchots are square wooden stakes, 5-6 m long and 10 cm wide, sunk 1 m deep in the foreshore. The stakes are made of exotic woods, most often *Lophira alata* and *Dinizia excelsa*, and are expected to last over 15 years. Bouchots are arranged in pairs of lines 100 m long and 25 m apart. The mussels must remain a minimum of 8 months on the bouchots. The beginning of harvest season occurs once the mussels have reached 4 centimeters in length and meet criteria of condition index and taste. This usually occurs in the first half of July. Mussels are harvested using hydraulic arms supported by amphibious boats, which scrape the whole mussel assemblage off, leaving the bouchots clean.

Water conditions in Mont Saint-Michel Bay are not suitable for natural reproduction of the blue mussel. Therefore, spat collection starts in March in the Bay of Biscay, mostly in the Charentes region. We described this stage using data provided by one producer, who is responsible for producing 300 km of seeded ropes each year. Producers construct temporary wooden structures on the lowest parts of chosen beaches and then extend ropes made from hemp or coconut fibers on these structures. The ropes remain in place for about two months before being brought to Mont Saint-Michel Bay by road.

Upon arrival, seeded ropes are coiled around free bouchots or laid out on temporary horizontal structures built on the foreshore until new bouchots are available. Once mussels start growing, producers stabilize the structure of the bouchot by progressively encasing each in 3-7 polypropylene nets, depending on the exposure of their sites. To reach the culture sites, producers use tractors, small aluminum boats or amphibious boats. Specific data collection on amphibious boats was performed at the main shipbuilding company.

After harvest, mussels are placed for at least 24 hours in an oxygenated purification pool. Water is pumped from the bay into a lagoon shared by all shellfish producers in the area. Afterwards, mussels go through a declumper, which separates the mussels from each other and shreds the ropes and nets. They are then cleaned in a brushing machine and calibrated, first mechanically, then by hand, to remove any other kind of waste (crabs, algae, broken mussels, etc.).

At this point, 20-30% of the production is discarded, mostly due to undersized mussels. These mussels are currently spread over the tractor roads in the bay. This practice serves two goals: stabilizing the roads in the sand and driving mussel predators away from the bouchots by giving them an easily available food source. Mussel spreading is currently under heavy debate and may soon be discontinued.

Mussels may then be put in 5, 10 or 15 kg polypropylene bags of "traditional" mussels and put up for sale. They may also pass through another machine that removes the byssus threads and be sold in 5, 10 or 15 kg polypropylene bags of "ready-to-cook" mussels, or 1 kg polypropylene trays of "ready-to-cook" mussels. LCA was performed on each type of packaging. However, this paper shows the LCA results for "ready-to-cook" mussel's bags only. Organic waste from cleaning and processing stages and all other types of waste are buried at the local landfill. Wastewater is returned to the ocean without any kind of treatment. All back ground data was extracted from the ecoinvent v2.2 database (Swiss Centre for Life Cycle Inventories 2010).

Mussel shells are composed of $CaCO_3$ and may be considered a carbon (C) sink if they are degraded slowly. According to Fry (2012) and considering that coastal seawater is saturated in $CaCO_3$ and that the Mont Saint-Michel Bay is shallow, we treated spread mussel shells as C sinks. Since other shells are expected to join ordinary household waste, we examined common waste-management options in France. Since 44.4% of French household waste ends up in landfills (ADEME 2008), we assumed that the shells of 44.4% of all mussels sold in France would be buried and act as a C sink.

Spread mussel flesh was excluded from our calculations since it belongs to a short cycle and did not influence overall nutrient balance of the bay. We calculated N and P exports based on the amount of mussel flesh present in marketed mussels. We also assumed increased biochemical oxygen demand of the water released into the bay due to organic-matter processing and bacterial decomposition of discarded mussels.

We estimated amounts of C, N and P in mussels (Table 1) based on Brigolin et al. (2009) and Chairattana et al. (2012). With data from the former, we excluded mussel respiration, considered as a short cycle in the bay, and calculated the amount of C sequestrated in mussel shells based on the balance of the remaining C flows. We supplemented this analysis with data from Chairattana et al. (2012), who showed that part of mussel shells is formed from dissolved CO_2, (not included in Brigolin et al.(2009)).

Table 1. Estimated C content in the shell, and N and P contents in the flesh, per tonne of blue mussels in the life cycle inventory.

Element in shell or flesh	Per tonne of harvested mussels
C in shell from ingested C (Brigolin et al. 2009)	198 kg C
C in shell from dissolved C (Chairattana et al. 2012)	18 kg C
N in flesh (Brigolin et al. 2009)	4.17 kg N
P in flesh (Brigolin et al. 2009)	0.38 kg P

2.3. Life cycle impact assessment

Impact categories were selected based on previous studies and guidelines in aquacultural LCA (Aubin et al. 2013; Pelletier et al. 2007): climate change (kg CO_2-eq), acidification (kg SO_2-eq) and eutrophication (kg PO_4-eq) were calculated using characterization factors of CML2 Baseline 2000 version 2.03 (Guinée et al. 2002). Energy use (MJ) was calculated according to the Total Cumulative Energy Demand (TCED) method, version 1.03 (Frischknecht et al. 2004). Water dependence (m^3) refers to freshwater use and was calculated according to Aubin et al. (2009). Calculations were performed with Simapro® 7.0 software.

2.4. Interpretation of results

Impacts of mussels at each production site for each producer were calculated independently (13 observations) and then aggregated. Variability in impacts was considered but not uncertainty due to foreground and background data. Contributions of different production stages of the system to the impacts were studied.

3. Results

Impacts of one tonne of ready-to-cook mussels varied according to production area and producer: acidification from 1.47-2.65 kg SO_2-eq, eutrophication from -1.69 to -0.85 kg PO_4-eq, climate change from -44.7 to 125.5 kg CO_2-eq, TCED from 7666-12,866 MJ, and water dependence from 92-98 m^3 (Table 2).

Table 2. Means and standard deviations (SD) of impacts calculated for 1 tonne of "ready-to-cook" mussels, depending on their location of culture within Mont Saint-Michel Bay.

	Center		East		Far East	
Impact	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Acidification (kg SO_2-eq)	2.24	0.25	2.29	0.26	1.59	0.15
Eutrophication (kg PO_4-eq)	-1.09	0.27	-0.98	0.14	-1.24	0.32
Climate change (kg CO_2-eq)	37.49	70.37	77.45	64.68	-6.56	34.81
Total cumulative energy demand (MJ)	11,360	1132	11,237	1599	8285	1069
Water dependence (m^3)	96.9	18.4	96.7	18.7	94.0	18.2

On-site transport was the main contributor to acidification and climate change impacts and a major one to TCED (Fig. 2). The culture stage greatly decreased eutrophication and slightly decreased climate change. Wooden stakes decreased climate change as much as on-site transport increased it. Wooden stakes were also an important contributor to TCED. The cleaning and packing stage was the main contributor to water dependence and a major one to TCED and eutrophication. The spreading of discarded mussels contributed markedly to eutrophication but slightly decreased climate change.

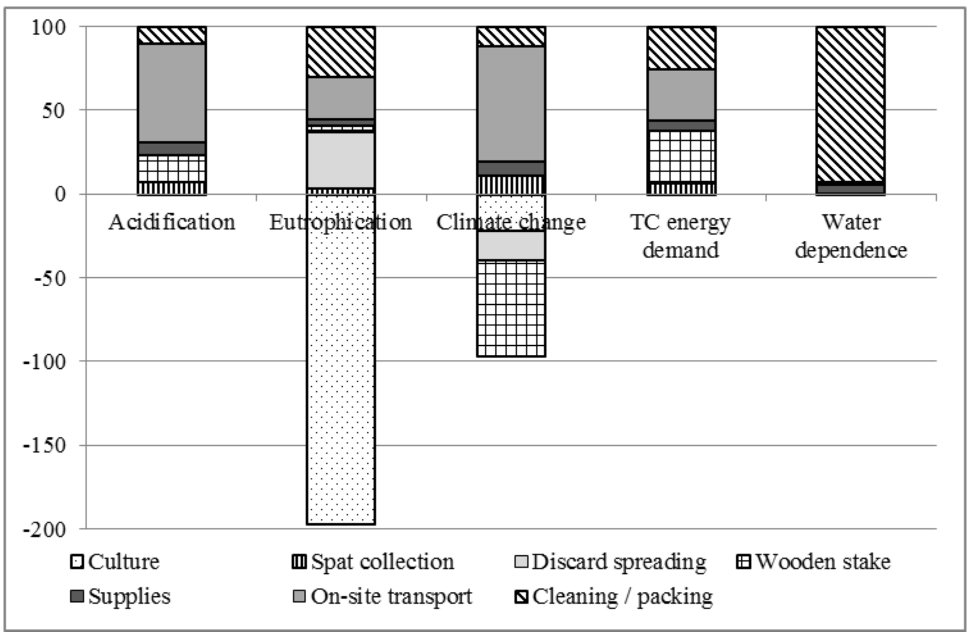

Figure 2. Contribution to environmental impacts of different stages of the production system of ready-to-cook mussels in Mont Saint-Michel Bay

4. Discussion

Assuming the uptake of N and P by mussel production induces a negative value for eutrophication impact, indicating a potential mitigating effect on water quality of the bay. Nevertheless, this favorable effect is low, around 1 kg PO_4-eq per tonne of "ready-to-cook" mussels, which should be compared to eutrophication impacts of other agricultural products produced in the Mont Saint-Michel region (e.g. 14 kg PO_4-eq per 1 tonne of pig live weight (ADEME 2013)). This result indicates a small but potential ability of mussel production to decrease eutrophication impacts due to livestock production at the territory level. This type of complementarity activity is also developed, for example, in integrated multi-trophic aquaculture for salmon production (Barrington et al. 2009).

Estimated climate change impact in this study showed high variability. On average, climate change impact is decreased first by the sequestered C in wooden stakes, then the spreading of discarded mussels, and then the burial of sequestered C in mussel shells in landfills. All of these processes, however, have high levels of uncertainty. Inventories from the ecoinvent database used to model exotic wood production are standard ones, and estimates of the wood's C sink effect are debatable. From this ecoinvent methodology, CO_2 assimilation is based on 49.4% of woods' C content. The percentage of household waste put into landfills may vary greatly depending on region and time period. Finally, the spreading of discarded mussels is about to be forbidden in Mont Saint-Michel Bay. In our case study, mitigation of climate change impact mainly compensates CO_2 emissions due to on-site transportation. At best, the bouchot blue mussel culture of Mont Saint-Michel Bay can be considered to produce little or no climate change impact but not as a C sink. Uncertainty analysis needs to be performed to assess the robustness of this conclusion.

In our study, impacts varied greatly according to the geographic location of bouchot sites. Two competing factors may explain this: mussel yield is higher in the Far East of the bay (due to ocean currents) than in the two other sites, but the Far East is further from on-shore infrastructure, and fuel consumption due to on-site transportation is a major contributor to impacts. As a consequence, we can observe negative values in eutrophication and climate change in the Far East area, where the production yields are the highest, inducing the highest nutrient uptake, and where the C fixing in shell over-compensate the CO_2 emissions of the rolling stock. This result has led the mussel producers' organization to revise their transportation strategy and the location of infrastructure.

5. Conclusion

Considering the chemical composition of mollusk flesh and shells to better describe their extractive capacity in the environment influences estimates of eutrophication and climate change impacts calculated with LCA. Results show a potential mitigating effect of blue mussel culture on water quality. A C sink effect due to mussel shell calcification was not confirmed, but a methodology that includes the composition and fate of shells during production processes and after consumption was developed. A similar approach should be performed on other production systems, other mollusks, and in other regions.

The bouchot culture of mussel is a low-impact activity, but fuel consumption to transport workers and mussels is a key point to analyze. Different environmental impacts in different locations suggest that efforts to render LCA increasingly spatially-explicit should be continued.

6. References

ADEME (2008). Le traitement des ordures ménagères en France en 2008. Online: http://www2.ademe.fr/servlet/KBaseShow?sort=-1&cid=96&m=3&catid=24147

ADEME (2013). Base de données AGRIBALYSE_vIMPACTs V1.1. Online: http://www2.ademe.fr/servlet/list?catid=25514

Aubin J (2013) Life cycle analysis as applied to environmental choices regarding farmed or wildcaught fish. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. 8 (11).

Aubin J, Papatryphon E, van der Werf HMG, Chatzifotis S (2009). Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment. J. Clean Prod. 17, 354-361

Barrington K, Chopin T, Robinson S (2009) Integrated multi-trophic aquaculture (IMTA) in marine temperate waters. In: Soto, D. (Ed.), Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper. No. 529. FAO, Rome, pp. 7-46

Brigolin D, Dal Maschio G, Rampazzo F, Giani M, Pastres R (2009). An individual-based population dynamic model for estimating biomass yield and nutrient fluxes through an off-shore mussel (Mytilus galloprovincial-is) farm. Estuarine, Coastal and Shelf Science, 82, pp. 365–376

Chairattana C, Powtongsook S, Dharmvanij S, Manasveta P (2012). Biological carbon dioxide assimilation process using marine phytoplankton Tetraselmis suecica and bivalve Perna Viridis. Environment Asia, 5 (1), pp. 63-69

Chamberlain J, Fernades T, Read P, Nickel T, Davies I (2000). Impacts of biodeposits from suspended mussel (Mytilus edulis L.) culture on the surrounding surficial sediments. ICES Journal of Marine Science, 58, pp. 411-416

Christenssen P, Glud R, Dalsgaard T, Gillespie P (2003). Impact of long line mussel farming on oxygen and nitrogen dynamics and biological communities of coastal sediments. Aquaculture, 218, pp. 567-588

Comité national de la conchyliculture (CNC) (2012). La production française. http://www.cnc-france.com/La-Production-francaise.aspx

FAO (2012). Mytilus edulis. http://www.fao.org/fishery/culturedspecies/Mytilus_edulis/fr

Frischknecht R, Jungbluth N, Althaus HJ, Doka G, Dones R, Hirschier R, Hellweg S, Humbert S, Margni M, Nemecek T, Speilmann M. (2004) Implementation of Life Cycle Impact Assessment Methods (version 1.1). Eco-Invent Report No. 3. Swiss Centre for Life Cycle Inventories, Dübendorf, 2004. 116 pp

Fry J (2012). Carbon footprint of Scottish suspended mussels and intertidal oysters. Scottish Aquaculture Research Forum, SARF078, pp. 1-56

Grant C, Archambault P, Olivier F, McKindsey C. (2012). Influence of ‘bouchot’ mussel culture on the benthic environment in a dynamic intertidal system. Aquaculture Environment Interactions, 2, pp. 117-131

Guinée JB, Gorrée M, Heijungs R, Huppes G, Kleijn R, de Koning A, van Oers L, Wegener Sleeswijk A, Suh S, Udo de Haes HA, de Bruijn H, van Duin R, Huijbregts MAJ (2002) Handbook on Life Cycle Assessment. An Operational Guide to the ISO standards. Kluwer Academic Publishers, Dordrecht, The Netherlands, 692 pp

Iribarren D, Moreira MT, Feijoo G (2010 a) Revisiting the Life Cycle Assessment of mussels from a sectorial perspective. J. Clean Prod. 18, pp 101-111

Iribarren D, Moreira MT, Feijoo G (2010 b) Implementing by-product management into the Life Cycle Assessment of the mussel sector. Resources, Conservation and Recycling 54, pp 1219-1230

Iribarren D, Moreira MT, Feijoo G (2010 c) Life Cycle Assessment of fresh and canned mussel processing and consumption in Galicia (NW Spain). Resources, Conservation and Recycling 55, pp 106-117

Jansen HM (2012) Bivalve nutrient cycling - Nutrient turnover by suspended mussel communities in oligotrophic fjords. Wageningen University, Wageningen, pp 152

Joint Research Centre (JRC) (2010) International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010. EUR 24708 EN. Publications Office of the European Union. Luxembourg. 417 p

Mettam GR, Adams, LB (2009) How to prepare an electronic version of your article. In: Jones, BS, Smith, RZ (eds) Introduction to the Electronic Age. E-Publishing Inc, New York, pp 281-304

Nizzoli D, Welsh DT, Viaroli P (2011). Seasonal nitrogen and phosphorus dynamics during benthic clam and suspended mussel cultivation. Marine Pollution Bulletin, 62, pp. 1276-1287

Pelletier NL, Ayer NW, Tyedmers PH, Kruse SA, Flysjo A, Robillard G, Ziegler F, Scholz AJ, Sonesson U, (2007) Impact categories for life cycle assessment research of seafood production systems: Review and prospectus. Int. J. Life Cycle Assess. 12, 414-421

Richard M, Archambault P, Thouzeau G, Desrosiers G (2006). Influence of suspended mussel lines on the biogeochemical fluxes in adjacent water in the Iles-de-la-Madeleine (Quebec, Canada). Canadian Journal of Fisheries and Aquaculture Science, 63, pp. 1198-1213

Strunk Jr W, White EB (2000) The Elements of Style, 4th edn. Longman, New York van der Geer J, Hanraads JAJ, Lupton RA (2010) The art of writing a scientific article. J Sci Commun 163:51-59

Swiss Center for Life Cycle Inventories (2010) Ecoinvent v2 Database. Ecoinvent Center (2010), Online: http://www.ecoinvent.ch/

Thrane M (2004) Energy Consumption in the Danish Fishery: Identification of Key Factors. Journal of Industrial Ecology 8, pp 223-239

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