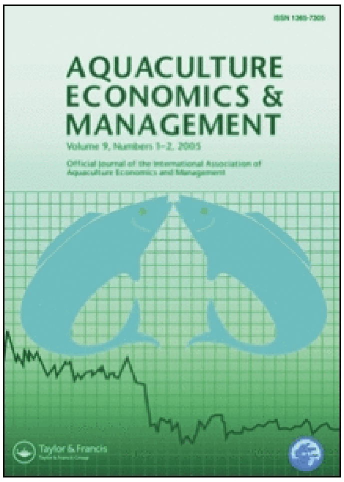

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MUSSEL CULTIVATION AS A CO-USE IN OFFSHORE WIND FARMS: POTENTIAL AND ECONOMIC FEASIBILITY

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☐ *More than 50% of the annual worldwide harvest of mussels is produced in Europe. The mussel cultivation in Germany is based on an extensive on-bottom culture and depends entirely on natural resources for food, spat and space. Due to stakeholder conflicts and a lack of spat availability, mussel farmers tend to move offshore where space is not limited and adequate settlement guaranteed. Newcomers – the offshore wind farmers – are covering large areas in the German Bight which in contrast give the opportunity to use these areas in a multifunctional way by accepting mussel cultivation within the wind farms. This study compiles the basic data for offshore mussel cultivation in close vicinity to a designated offshore wind farm in the open sea of the German Bight and employs different case-scenario calculations to illustrate the impact of changing parameter values on overall profitability or non-profitability of this activity. Primary focus is placed on the production of consumer mussels but seed mussel cultivation is also taken into consideration. We show that production of consumer mussels with longline technology is sufficiently profitable even under the assumption of substantial cost increases. This is especially true, if existing capacities could be used. The cultivation of seed mussels depends on the possibility of using existing equipment. A substantial increase of seed mussel prices to at least 0.6€, given the main cost categories remaining constant, turns this alternative into substantial profitability. This study concludes with providing some recommendations on how favorable terms or actions could further improve profitability of offshore mussel cultivation. Altogether, our results are intended to shed some light on business management topics that future offshore mariculture operators such as traditional mussel farmers should follow in order to be efficient.*

Keywords blue mussel, co-use, economic feasibility, *Mytilus edulis*, offshore aquaculture, offshore wind farms

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INTRODUCTION

Development of Mussel Production

The blue mussel *Mytilus edulis*, and to some extent the Mediterranean mussel *M. galloprovincialis*, are native species in most parts of the northern hemisphere which are hardy, readily seed themselves in the wild, require no feeding, grow fast, provide nutritious and tasty human food and are available year round (Seed & Suchanek 1992; Gosling 2003). Therefore, Hickman (1992) described these mussels as having those characteristics that make them an "ideal candidate for aquaculture." In Europe, mussels have been caught, consumed and sold from the wild for centuries. Since the early 1950s, however, the demand for bivalve products for human consumption has exceeded the supply from fisheries production, which led to an increase in marine aquaculture (e.g., Smaal, 2002; FAO, 2007).

Total production of mussels over the last few years was approximately 1.96 million metric tons per year (FAO, 2007). Denmark is the only country in the world that still produces large quantities of wild harvest mussels. The majority of mussel production originates from marine aquaculture (approximately 1.9 million tons in 2006) and dates back to the 13th century. That was the time when French aquaculturists started the first pole ("bouchot") culture along the Atlantic coast (Dardignac-Corbeil, 1979). In Europe, more than 20 countries produce nearly a third of the total global aquaculture production of the two main mussel species, with Spain, France, and the Netherlands being the leading countries (FAO, 2007). Expansion of demand in world markets, particularly for blue mussels, has resulted in increased production in many parts of the world (especially in Norway and Sweden, Ireland, South Africa and North America) (Hoagland et al., 2003).

Mussel Cultivation in Germany

Total mussel production in Germany has varied from 5,000 and 50,000 annual tons within the last 20 years in States bordering the German Bight (State of Lower-Saxony and State of Schleswig-Holstein) (Figure 1) and is based on bottom-culture techniques for raising blue mussels (Seaman & Ruth, 1997). This method depends on the bioavailability of seed mussels obtained from wild beds in the coastal sea. Mussels are gathered with dredges from natural intertidal and subtidal habitats and transferred to licensed culture plots in the *Wadden Sea*, where environmental conditions are suitable for optimal growth and fattening. These mussels reach a marketable size of about 50–60 mm in approximately two years (Van Stralen & Dijkema, 1994). Finally, the majority of the mussels will be transferred to

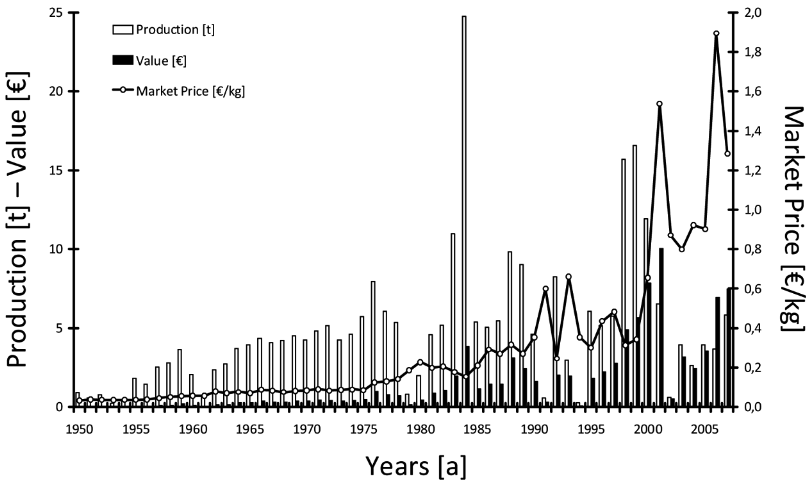

FIGURE 1 Production and values of cultivated blue mussels (*Mytilus edulis*) in Lower Saxony only (Germany) in the years 1950–2007 (SFA 2008). The fluctuations are due to variations of the recruitment success and the availability of spat. The continuous black line displays the market price (nominal) of blue mussels (*Mytilus edulis*) in the respective year.

Yerseke (the Netherlands) and kept in the *Eastern Scheldt* for de-sanding and will be sold afterwards at the local auction (personal communication with Brandt from the State Fisheries Agency [SFA], Niedersächsische Muschelfischer, 2009). In the years 2007 and 2008 the annual consumption of mussels in Germany ranged between 20,000 and 37,000 tons, which is equivalent to a per-capita consumption of approx. 0.25–0.45 kg (Neidigk, 2009).

Some disadvantages of bottom culture are that the mussels are subject to higher predation pressure from eider ducks, starfish and crabs (e.g., Dolmer, 1998; Hamilton et al., 1999; Leonard et al., 1999). Furthermore, this technique depends on the availability of seed mussels from the wild (e.g., Korringa, 1976; Buck, 2007a). Unfortunately, due to poor recruitment over several years, the amount of catchable spat decreased thus influencing mussel aquaculture production in Germany (Walter & Liebezeit, 2003). Further, the geographic distribution of mussel beds is rather patchy and their existence is subject to movement due to predation, current regimes, and storm events.

Walter and Liebezeit (2001, 2003) commenced research into whether or not suspended culture techniques could be used to obtain seed mussels in a nearshore area of the Jade estuary. They found that spat can be obtained even in years with a low spat fall when using the floating longline technique, commonly described as off-bottom culture (Hickman, 1992). Due to conservation measures applied to nearly 98% of the German North

Sea coast, the development and expansion of the mussel aquaculture sector is limited insofar as the current area of mussel culture plots will not be enlarged (CWSS, 2008). In addition to the regulations already existing for culture lots, the highly competitive users along the German coastal sea hamper the development of suspended culture techniques (Buck et al., 2004). A possible solution may be to move off coastal areas to the open ocean where there is adequate space and fewer conflicts (Buck 2002, 2007b).

Moving Mussel Production Offshore

Within the last decade, interest has grown in investigating the potential for larger-scale aquaculture operations in the open ocean, of offshore aquaculture. Worldwide, offshore aquaculture is a new and emerging scientific field (e.g., Polk, 1996; Hesley, 1997; Stickney, 1998; Bridger and Costa-Pierce, 2003) and describes the cultivation of aquatic organisms not only far from the coast but also exposed to all conditions of the seas (Ryan, 2005). Fish cages and mussel longlines resistant to offshore conditions were installed in some countries some years ago (Langan, 2001; Langan & Horton, 2003). Two pilot projects (one organized and run by UNH scientists off the Isles of Shoals in the western Gulf of Maine and one by WHOI scientists off Martha's Vineyard in Rhode Island Sound) have demonstrated the biological and engineering feasibilities of this new kind of technology. However, there is only one pilot-scale offshore mussel farm in the world (Langan & Horton, 2003).

In the German Bight harsh weather conditions hamper the installation of common technologies. Offshore wind farming has been proposed for co-use with aquaculture (Buck, 2002, 2004). Establishment of offshore wind farm turbines provides space and attachment devices for mariculture facilities and therefore minimizes the risks originating from high-energy-environments (Buck et al., 2006).

Advantages of performing mussel cultivation activities within offshore wind farm territories are manifold. Placement of mariculture devices in defined corridors between wind farm turbines reduces the special need through multiple use of ocean territories (Michler-Cieluch et al., 2009a). Also, infrastructure for regular servicing may be shared. Both industries require multi-use sources of transportation, preferably with lifting capacities to install and change plant components. This provides an opportunity for both enterprises to share these high-priced facilities (Michler-Cieluch et al., 2009b). Also, there are options to link individual activities of both activities. For instance, charter contracts for specially designed mussel harvesting vessels could be aimed as a solution for transporting wind farm technicians to the offshore location at times of planned, preventive operation and maintenance activities (Michler-Cieluch et al., 2009b). Further, a combined environmental impact assessment for both users would save costs.

Altogether, the viability of a mussel cultivation enterprise within offshore wind farming areas depends on various factors such as (1) the technological and biological feasibility, (2) the legislative and regulatory constraints, (3) the environmental sustainability of farming aquatic organisms, and (4) the profitability of this potential commercial operation (see review by Buck et al., 2008). The present article is concerned with the last of these issues and focuses on the economic aspects of commercial longline mussel cultivation in German offshore waters.

Focus of the Study

This article provides a first insight into financial considerations associated with moving mussel cultivation close to German offshore wind farms, aiming to demonstrate the commercial potential from an economic perspective of a new enterprise that has not yet become established even on a pilot scale. By defining the most relevant parameters that have an impact on potential commercial exploitation, we sketch an investment appraisal, an enterprise budget analysis, a break-even analysis, and a sensitivity analysis of various scenarios to evaluate economic profitability of mussel cultivation offshore.

The principal target group is the traditional mussel farmer community, operating nearshore bottom-culture plots. In addition to the scarcity of space in coastal areas, the bottleneck in the cultivation cycle of mussels is the availability of seed mussels (Walter & Liebezeit, 2003). Therefore, we examine not only aspects of marked-sized mussels ready for consumption but also point towards the economic viability of offshore cultivation of tiny seed mussels, which can later be used to supply the farmer's bottom-culture sites.

MATERIALS AND METHODS

The offshore wind farm "Nordergründe" designated for the coastal sea of the Federal German state of Lower Saxony serves as a prime example for this economic study. The farm is still under construction and will be ready for operation in 2011 (Energiekontor, 2009).

Description of Study Site and Environmental Conditions

The construction site of the offshore wind farm "Nordergründe" is in the outer estuary of the river Weser between the fixed marine

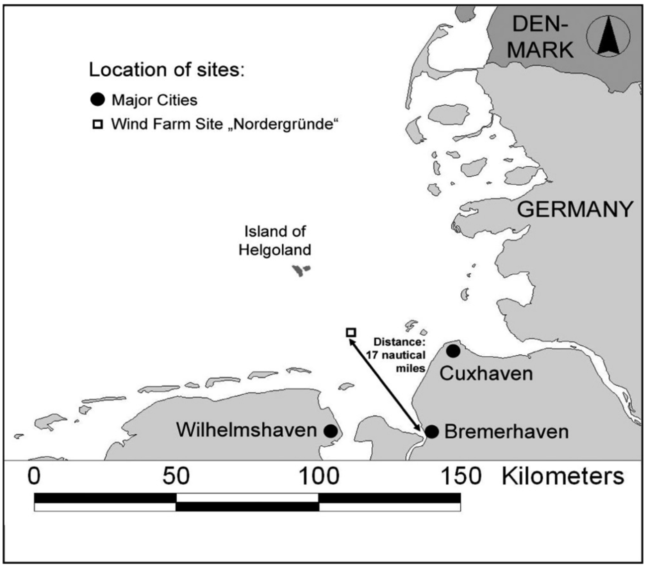

FIGURE 2 The German Bight with the cities of Bremerhaven, Cuxhaven and Wilhelmshaven. The small box indicates the location of the wind farm Nordergründe, 17 nautical miles off Bremerhaven.

facilities and navigation marks of “Alte Weser” and “Tegeler Plate” (53°49,9′ N - 8°8,7″ E), 17 nautical miles off the coast northwest of the city of Bremerhaven (Figure 2). The site is characterized by various hydrographical features that include depth (10–15 m), condition of the sea bottom (soft bottom), salinity (20–33‰), turbidity and light (high sediment load), wave climate (exposed), current velocity (0–1.2 m/s), significant wave heights (0–6 m), nutrients (eutrophic situation), water temperature (1.5–18°C) and wind velocities (up to 8 Beaufort), which are reviewed in Buck (2004) and Buck et al. (2008).

Research Status of Offshore Aquaculture Cultivation in this Area

Many studies have analyzed the use of this particular area for the cultivation of candidate species, such as blue mussels (*Mytilus edulis*), Pacific and European oysters (*Crassostrea gigas, Ostrea edulis*), and sugar kelp (*Laminaria saccharina*) (Buck, 2002, 2004). These studies included examination of the biology of the organisms, the development of resistant techniques and their design-engineering attachment with the grounding constructions of offshore wind turbines, the need for offshore co-management arrangements between the involved actor groups, and studies on the regulation of aquaculture operations in offshore sites (Buck, 2004; Buck et al., 2008; Michler-Cieluch, 2009b). Altogether, results point towards a highly complex and interdependent approach but identify promising steps for establishing prospective offshore multiple-use settings. But, “no one should get involved in shellfish production if they don’t plan on making profit” (Bornadelli and Levesque, 1997); thus economic research related to commercial exploitation of a species is indispensable.

Specification of the Subject and Data Collection

For the purpose of reducing complexity in an economic analysis that is still of a hypothetical nature, we confine the examination in the present study to a single candidate, the blue mussel, and to one particular technology, a submerged longline. We assume that this enterprise will be established in the territory of the offshore wind farm Nordergründe. This kind of offshore mussel cultivation serves as a prime example to calculate cash flows as well as costs and returns of offshore longline cultivation. Since the motivation to carry out this study was mainly driven by bottom-culture farmers (Ewaldsen, 2003) who were searching for alternatives to overcome the problem of continuous spat availability (Walter & Liebezeit, 2003), we presume this group to be the principal target group that will be conducting offshore cultivation in the near future. Today’s farmers have been involved in traditional bottom-culture techniques for numerous generations. Hence, they are well experienced with the biology and cultivation of mussels, with the work at sea, the harsh weather conditions, and their vessels are already equipped with many tools necessary for an offshore operation.

The study group “MytiMoney” conducted data collection. This study group is part of the co-operative research project *Coastal Futures*, which is financially supported by national and international scientific institutes, national authorities and State Ministries (Federal Ministry of Education and Research [BMBF]; Grant No. 03 F 0404). The joint research project brings together a total of 50 project partners (Kannen, 2004). The MytiMoney-Group obtained data from various sources including (1) the industry (shipping, wind farm operators, aquaculturists, etc.), (2) experts of the seafood market, (3) authorities (Water and Shipping Agencies, State Fisheries Agencies), (4) management consultancies, and (5) from (peer-reviewed) literature. Local management consultancies and economic experts supported data gathering and evaluation.

Economic Analysis

The economic analysis consists of an investment appraisal by calculating the net present values (NPV), the internal rate of return (IRR), an enterprise budget analysis, a break-even analysis, and a sensitivity analysis of changes of the most important parameters. All numbers are in real terms, and taxes were not considered. These approaches are common in aquaculture economic studies (e.g., Hatch and Tai, 1997; D'Souza et al., 2004; Engle et al., 2005; Pomeroy et al., 2006; Whitmarsh et al., 2006; Liu and Sumaila, 2007). According to the operating life expectancy of main components of the longline harness we calculate the enterprise budget for a four-year life cycle. Cultivation of mussels for consumption as well as for seed exhibit different costs and revenues, and both alternatives will be assessed. Additionally, a new vessel as well as the possibility of using existing capacities of the mussel farmer community in Lower Saxony will be taken into consideration.

This led to four different scenarios. First, we assume a basic scenario for the farming of consumption mussels with a new appropriate vessel as well as a new land facility. In a further scenario the above-mentioned existing capacities of mussel farmers will then be addressed. Afterwards, both alternatives will be assessed for seed mussel cultivation, respectively.

The economic analysis is organized as follows: 1) basic parameters for farm size, culture technology and biomass gain are described; 2) time schedule of the farm set-up and harvest operations is presented; 3) basic data on costs and investment are specified; and 4) finally a sensitivity analysis is outlined.

Basic Parameters for the Farm Size, Culture Technology and Biomass Gain. According to the current construction status of the German wind farm company "Energiekontor AG", 18 wind energy turbines of the 5 MW class will be installed in the offshore wind farm Nordergründe (IWR, 2008, Figure 3a). Assuming 1,000 m spacing between each turbine in all directions and

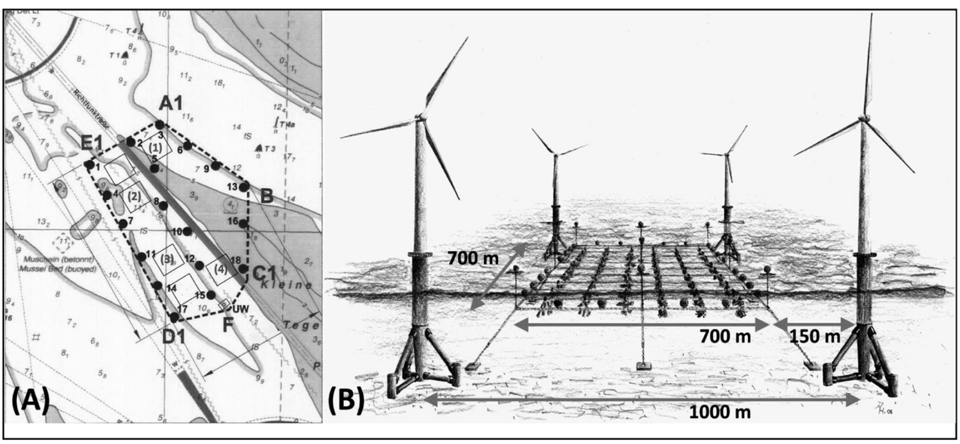

FIGURE 3 Planned wind farm Nordergründe. Figure (A) shows the map of the area (bird's eye view) displaying 18 offshore wind turbines (numbers without brackets) and six single mussel plots designated by the wind farm company. Four of these six designated plots were calculated according to our mussel cultivation projections (numbers in brackets). Figure (B) presents a design of a single mussel plot within a group of four wind turbines (not to scale) (modified after Michler & Kodeih 2007; Buck, own data).

TABLE 1 Basic Data for the Offshore Site Nordergründe

Details of the Mussel Farm	Value
Distance to the City of Bremerhaven	17 nautical miles
Number of wind turbines	18 (5 MW class)
Distance between turbines	approx. 1,000 m
Minimum spacing between turbines and any aquaculture co-use	150 m
Size of aquacultural area (single mussel plot)	$700 \times 700\,m = 490{,}000\,m^2 = 0.49\,km^2 =$ 49 ha = 121 acre)
Number of single mussel plots	4 (=196 ha = 484 acre)

taking into account a safety zone of 150 m around each wind turbine for servicing and security purposes, the remaining 700 m between two turbines could be used for aquaculture purposes (Figure 3b). Consequently, the area in between four wind turbines will be $700 \times 700\,m = 490{,}000\,m^2 = 0.49\,km^2 = 49\,ha$ (equivalent to approx. 121 acre, Table 1). This size is defined as a single mussel plot.

According to Figure 3a/b, four of the six designated plots were calculated according to our mussel cultivation approach with a purchase of a new vessel (Kite-Powell et al., 2003) resulting in a total farm size of about 196 ha (equivalent to approx. 484 acre, Table 1). Figure 3a shows two more mussel plots for future expansion but these plots were not included in our calculations. The remaining "empty" fields are shipping routes or service areas and cannot be used for aquaculture production (Buck et al., 2004; Gloy, 2006).

The following calculations are based on submerged longlines for mussel cultivation 5–7 meters below the water surface to avoid the destructive effects of surface waves. At this depth the entire cultivation harness does not touch the seabed, thereby reducing predation pressure by, for example, birds or starfish and guaranteeing a sufficient settlement success of mussel larvae (Walter & Liebezeit, 2001, 2003). Regarding a single mussel plot, the length of a horizontal longline is approx. 700 m. The longline (Figure 4) has, at both sides, a 15 m-"unusable segment" (Bornardelli, 1996), which cannot be retrieved when sampling or harvesting, resulting in a "productive longline" of 670 m. Within a single mussel plot, longlines will be installed in a parallel manner accepting a distance of 10 m between each other. This leads to 71 longlines with a total length of approx. 47,570 m ($71 \times 670\,m$). For simplification purposes, we calculate four mussel plots as a first commercial unit (altogether 284 longlines), following Kite-Powell et al. (2003) that one vessel is capable of servicing a field of 300 longlines.

The mussel collector harness consists of 335 V-shaped collector pairs (*Christmas tree type*), each consisting of two 2.5 m side pieces (Figure 4). All collector pairs are connected in series and are suspended in a perpendicular fashion from the longline. The total length of the collector harness

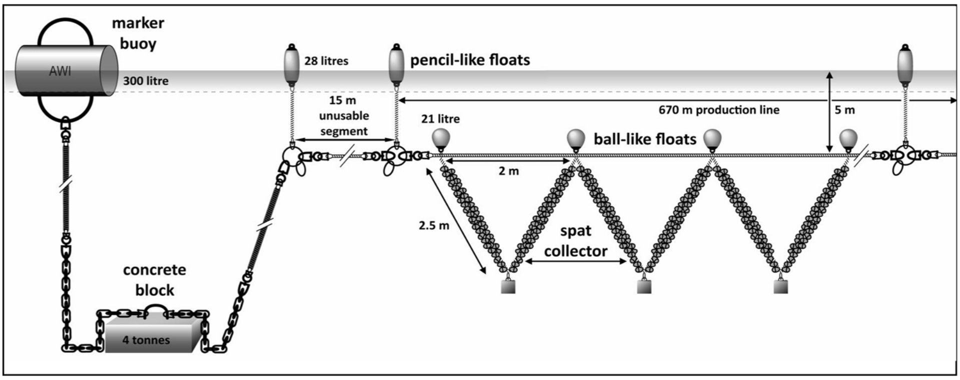

FIGURE 4 Example of a submerged longline system design with a V-shaped spat collector harness. In this image only a part of the 700 m long longline is presented (not to scale).

per longline is approximately 1,675 m (335 V-shaped collector pairs having each a length of $2 \times 2.5\,\text{m} = 5\,\text{m}$), which amounts to 118,925 m ($71 \times 1{,}675$) per single mussel plot, respectively.

According to Walter (2004), Walter and de Leeuw (2007) and Buck (2007b), the biomass of mussels per meter of collector varies between 10 and 15 kg. Calculating (at 10 kg/m) the production per single longline would be approximately 16.75 metric tons ($1{,}675\,\text{m} \times 10\,\text{kg}$) and approximately 1,190 metric tons per single mussel plot ($71 \times 16.75\,\text{t}$), respectively.

Time Schedule of the Farm Setup, Maintenance and Harvest Operations. Maximizing onshore activities results in the best and safest working conditions (Sørensen et al., 2001). Therefore, the setup of the 284 longline harnesses (providing settlement and grow out for four mussel plots), is assumed to take place onshore. After preparation (excluding anchors), the complete harness will be transferred to the farm site and deployed at sea during the spring to allow settlement in May of the same year. Figure 5 shows the

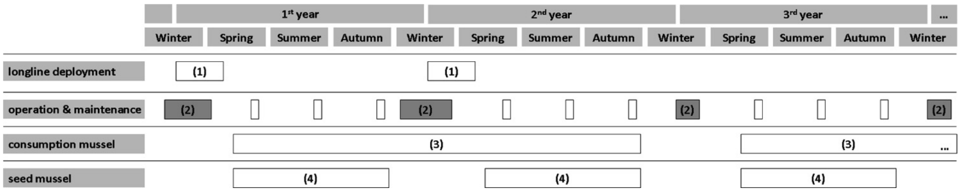

FIGURE 5 Example for a production cycle modified after Danioux et al. (2000). Blank boxes indicate the respective time slot for a specific work. (1) Indicates the deployment of longlines, (2) describes the work in the land-based facility (grey boxes) and operation and maintenance work at sea (blank boxes). (3) shows the production cycle for consumption mussels from the post-larval settlement (around May) until market size (around September in the following year), and (4) displays the annual spat production starting with settlement (around May) and harvest of tiny seed mussels (around August–September in the same year). Secretarial work is not included.

time slots for deployment of longlines, their operation and maintenance works, and the production cycle for consumption and seed mussels.

Due to the large quantity of longlines per mussel plot, two full mussel plots are planned in the first year (only 142 longline harnesses). This will be scaled up in the following year so that 284 longlines (equivalent to four mussel plots) will operate at full scale. Later, the exchange of longline devices before or after the expiration of the operating life expectancy can automatically be reduced during or after the maintenance or routine harvest procedures. Cultivation of mussels for consumption and for seed has different growth periods. Consumption mussels will reach market size after approximately 1.5 years, while seed mussels can be harvested after 5–6 months. Due to the fact that the farm will operate at full scale in the second year a form of *shifting cultivation* will take place (Bartlett 1956). Harvest of plots will take place biennially (Table 2). A total of two plots used for the cultivation of consumption mussels can be harvested each year. However, only in the first year of the enterprise no mussels can be harvested due to the growth period of the mussels to reach market size. This amounts to eight harvests for a typical period of four years. Seed mussels, however, can be gathered of two culture plots in the first year and of four plots thereafter. That leads to a harvest of 16 culture plots in a typical four-year period.

Once the longlines are in place the production operations undergo the following cycle:

Year 1: Spat collection (around May–June)
Year 1–2: Maintenance of longlines to remove fouling organisms and modify buoyancy (August–May)
Year 2: Grow-out to consumption size within 15–18 months (market size is above 5.5 cm) and harvest in August–November

In the case of seed mussel production, mussel plots can be harvested every year (Table 2) and will take place as follows:

Year 1: Spat collection (around May–June)

TABLE 2 Time Schedule of the Farm Setup and Harvest Operations (Modified after Hoagland et al. 2003)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	All Following Years
Longline construction							
– moored	142	142	–	–	142	142	–
– installed	142	284	284	284	284	284	284
Lines harvested							
– consumption mussels	142	284	284	284	284	284	284
– seed mussels	142	284	284	284	284	284	284

Year 1: Harvest in August–September and supply nearshore on-bottom cultures

Basis Data on Costs and Investment. All costs were itemized by scenarios of production for consumption or for seed mussels. Calculation of costs are based on data gathered from existing traditional nearshore mussel cultivation activities since basic preconditions for nearshore and offshore culture schemes are quite similar. There are around 30 traditional mussel culture plots (on-bottom method) in the coastal sea of Lower Saxony (Niedersächsische Muschelfischer, 2009) with a total size of around 1,300 ha (CWSS 2008); hence a mean culture plot is approximately 45 ha, similar to that of a prospective single mussel plot offshore with 49 ha (Table 1). Nearshore cultivation plots have a distance of 10–55 nautical miles to the port of transshipment, which is within the scale of the planned offshore site (17 nautical miles) (BSH, 2008).

Offshore operations are more labor and time intensive than nearshore sites. Much of the labor is for maintenance that includes deploying or retrieving of moorings or other parts of the construction harness, which may lead to generally higher operation and production costs. However, some production steps necessary for nearshore operations cease to exist offshore, which in turn leads to cost reduction. For example, in the case of offshore mussel production for consumption, there is no need to dredge seed mussels from natural beds in order to deploy them on bottom-culture plots. Additionally, no re-seeding and de-sanding costs are incurred for offshore cultivated mussels. Such mussels are cultivated in a suspended mode in the water column, which leads to the absence of sand originating from the sea floor of the Wadden Sea.

The annual fixed costs consist of depreciation, licenses, motor overhaul, interest on fixed capital and miscellaneous costs like insurance premium and administrative cost. Interest rate is assumed to be 7%. Variable costs are fuel expenses, wages, repairs and maintenance, miscellaneous costs and interest on variable costs. Fuel was assumed to cost 0.55 € per liter, wages are calculated with 3,333 € per month.

When using existing capacities of mussel farming in Lower Saxony, an investment for retrofitting at the beginning of the enterprise will be required. In the scenarios where new capacities have to be established, investment into a new appropriate vessel as well as into a new land facility is considered. All other costs are assumed to be similar to those used for the basic scenario.

Sensitivity Analysis. A sensitivity analysis is used to explore the effects of changes in the key parameters that reflect uncertainty. The main internal source of uncertainty is the biomass gain. The main external source of uncertainty is the development of costs and prices. In our sensitivity analysis we calculate NPV and IRR for different mussel prices, different biomass gain, different developments of single cost components as well as an increase in overall costs. The effect of different discount rates on NPV is also presented.

RESULTS AND DISCUSSION

Gross Receipts

Following the data of the Federal Agency for Agriculture and Food (2007) and the State Fisheries Agency, Bremerhaven, Germany (SFA) (2008), the average market price per kg of consumer mussels has been relatively stable until 1975 (below 0.2 €[1]/kg). Afterwards, the price has been subject to fluctuations ranging between 0.50–1.96 € (Figure 1). According to the development of the market price of blue mussels a price of 1.0 € per kg of mussels was used in the base scenario (SFA, 2008). Thus, a single longline could have a production value of 16,750 € (1,000 € × 16.75 metric tons) and a single mussel plot of approx. 1,190,000 € (1,000 € × 1,190 metric tons; Table 3).

Fixed Costs

The cost of longlines including the complete harness will be the sum of various individual costs and levels around 15.80 € per meter of longline (Table 4). Costs include collectors, mooring constructions, connecting pieces for the entire longline device (shackles, swivels, rings, etc.), and the complete buoyancy. Costs were calculated by Sahr (2006) using the equations for the definition of key cost data published in Pelz (1974). This leads to an overall investment cost of approximately 835,500 € per single mussel plot every four years (Table 4). In line with the estimates of Whitmarsh et al. (2006) the operating life expectancy is assumed to be four years for longlines and collectors, six years for buoyancy, and 10 years for anchors (Table 5).

A vessel adapted for performing offshore operations is needed. In our base scenario, we assume investment in a new vessel (45 m class, 430 BRZ, 500 KW) for around 4 million € (Sahr, 2006), including all necessary equipment for longline cultivation. This case also includes a complete motor overhaul after 10 years with 385,000 € (assuming motor costs to be 17.5%

[1]According to the European Central Bank (ECB) in Frankfurt/Main in Germany (2009) the exchange rate of European Euro [€] to US Dollar [$] ranged from 1.2555 to 1.5090 in 2009 (1 € = 1.2555 US $, resp. 1 € = 1.5090 US $).

TABLE 3 Basic Data for the Longline Construction

Item	Value
Longline:	
Depth	5–7 m
Length of a single longline	700 m (total) - 670 m productive longline - 2 × 15 m "unusable segment"
Distance between parallel longlines	10 m
Number of parallel longlines per single mussel plot	71
Total length of longlines per single mussel plot	47,570 m
Collectors:	
Spacing between collectors within a V-shape	2 m
Spacing between V-shapes	0 m
Number of V-shapes	335
Length of collectors/V-shapes	−each collector: 2.5 m - each V-shape: 5 m - per longline: 1,675 m (335 × 5 m) - per single mussel plot: 118,925 m (71 × 1,675 m)
Mussel plots:	
Number of calculated plots	4
Production values:	
Biomass per meter of collector	10 kg
Biomass per single longline	approx. 16.75 tons
Biomass per single mussel plot	approx. 1,189 tons
Market price per kg of mussels	1.0 €[a]
Potential value of a single (or four) mussel plot(s)	1,190,000 €[a] (4,760,000 €[a])

[a]According to the European Central Bank (ECB) in Frankfurt/Main in Germany (2009) the exchange rate of European Euro [€] to US Dollar [$] ranged from 1.2555 to 1.5090 in 2009 (1 € = 1.2555 US $, resp. 1 € = 1.5090 US $).

of total vessel investment and retrofitting to be 55% of the amount of 17.5%; Sahr, 2006) (Table 5). Because the mussel farmer community already disposes of mussel farming cutters used for bottom culture, we also calculate NPV with the assumption of using existing capacities of mussel farmers. Investment will then be reduced to the retrofitting of the vessel only, which was calculated with costs of about 750,000 € (Sahr, 2006).

Capital investment costs include the costs of a land facility for the purpose of equipment storage and for carrying out land-based activities such as tying and repairing collectors and other equipment. Investment costs for a land facility are assumed to be 1,500,000 € (Table 5). Licensing costs for a single mussel plot at the offshore site Nordergründe is based upon the scale of charges and fees of the State of Lower Saxony (NKüFischO, 2006). Following the fees for mussel license areas, only the bureaucratic work load will be charged, which was calculated by the State Fisheries Agency in Bremerhaven with a nonrecurring charge of approximately 1,000 € (personal communication with Brandt from SFA) (Table 5). Miscellaneous fixed costs (e.g., insurance premiums) are assumed to be 5% of

TABLE 4 Calculation of Investment Costs for Equipping a Single Mussel Plot with Longline Constructions

	Length [m]	–Distance Between Longlines –Distance Between V-shapes, Buoys, Moorings, Others [m]	Numbers Per Longline [n]	Number of Longlines Per Mussel Plot [n]	–Length of Longlines Per Mussel Plot [m] - Number Mussel Plot [n]
Longline[a]	670	10	–	71	47,570
Longline[b]	30	10	–	71	2,130
Collectors[c]	2.5	2	–	–	118,925
Buoyancy[c]	0.1	10	71	–	5,041
Stones/anchors[c] (mooring)	0.01	100	8	–	568
Others[c]	1	1	700	–	49,700
	Material costs per meter [€[d]]	*Installation costs per meter* [€[d]]			**Sum of costs per meter** [€[d]]
Longline[a]	2.0	0.5			2.5
Longline[b]	2.0	0.5			2.5
V-shapes/collectors	2.0	0.5			2.5
Buoyancy	3.0	1.0			4.0
Stones/anchors (mooring)	2.3	1.0			3.3
Others	1.0	–			1.0
				Total	15.80
					Investment costs per mussel plot [€[d]]
			Longline[a]		118,925
			Longline[b]		5,325
			V-shapes/collectors		297,313
			Buoyancy		200,930
			Stones/anchors (mooring)		163,300
			Others		49,700
			Sum investment costs per mussel plot		835,493

[a]Longlines where the collector harness can be attached;
[b]Longlines where the collector harness cannot be attached (2×15 m unusable segment);
[c]Per meter longline;
[d]According to the European Central Bank (ECB) in Frankfurt/Main in Germany (2009) the exchange rate of European Euro [€] to US Dollar [$] ranged from 1.2555 to 1.5090 in 2009 (1 € = 1.2555 US $, resp. 1 € = 1.5090 US $).

TABLE 5 Investment and Annual Depreciation for the Establishment of Four Mussel Plots

Components	Description	Quantity	Unit Cost [€[a]]	Total Cost [€[a]]	Years of Useful Life[b] [a]	Annual Depreciation [€[a]]
New vessel	mussel cutter for longline purposes incl. 500 KW Motor	1	4,000,000	4,000,000	20	200,000
Land facility	land and building for storage, constructing and offices	1	1,500,000	1,500,000	15	100,000
Motor	overhaul of 500 KW motor after 10 years	1	385,000	385,000	10	38,500
Longline		198,800	2.5	497,000	4	124,250
V-shapes/collectors		475,700	2.5	1,189,250	4	297,312.5
Buoyancy		20,164	4.0	80,656	6	13,442.67
Stones/anchors		2,272	3.3	7,497.6	10	749.76
Longline: others		198,800	1.0	198,800	10	19,880
License		1	1,000	1,000	20	50

[a]According to the European Central Bank (ECB) in Frankfurt/Main in Germany (2009) the exchange rate of European Euro [€] to US Dollar [$] ranged from 1.2555 to 1.5090 in 2009 (1 € = 1.2555 US $, resp. 1 € = 1.5090 US $);

[b]"Years of useful life" is the expected operational life of a producer durable good. Number of years indicates the time before it needs replacing.

depreciation leading to a total sum of 151,127 € in four years. Interest on fixed capital is 232,951 € for a four-year period. Total fixed costs were 3,560,817 Euro (Table 6).

Operation and Production Costs

Table 6 compiles the relevant costs for the base scenario. The experience of the bottom-culture aquaculturists indicates that approximately 70 days per year are needed for labor at four culture plots, amounting altogether to 280 offshore working days in four years. Taking into account 61.8% of full load engine performance in a 24 h day, fuel costs per day at sea are estimated to be 1,200 € (Gloy, 2006; Sahr, 2006). This totals 84,000 € per year or 336,000 € in four years.

Two full positions and two seasonal employees are required per year. The latter are employed only in times of the heaviest workload in the 6 months from spring to autumn. Labor costs total 479,952 € in a four-year period. Costs of maintenance and repairs, estimated as 10% of the yearly depreciation, are 302,254 €. Miscellaneous variable costs are estimated to be 5% of depreciation, total 151,127 € in four years. Interest on operating capital sums to 88,853 € in four years. Total variable costs were 1,358,186 Euro (Table 6).

TABLE 6 Enterprise Budget for a Four-Year Production Cycle

	Description	Unit	Quantity	Price/Unit	**Total value**
Gross revenue		tons	9,514	1,000	**9,514,000**
Variable costs					
Fuel	0.55 €[a] per liter	days	280	1,200	336,000
Wages	3,333 €[a] per man-month	income/month	144	3,333	479,952
Repairs/maintenance	calculated as 10% of depreciation	total	1	302,254	302,254
Miscellaneous	calculated as 5% of depreciation	total	1	151,127	151,127
Interest on operating capital	assumed to be 7%	total	1,269,333	0.07	88,853
Total variable costs					**1,358,186**
Fixed costs					
Licenses	1,000 €[a] for four plots	total	1	200	200
Depreciation on vessel	45 m class, 430 BRZ, 500 KW	total	1	800,000	800,000
Miscellaneous	telephone, insurance etc. (5% of depreciation)	total	1	151,127	151,127
Depreciation on longlines	see Table 4	total	1	1,822,540	1,822,540
Motor overhaul after 10 years	calculated with 385,000 €[a]	total	1	154,000	154,000
Depreciation on land facility	calculated with 1,500,000 €[a]	total	1	400,000	400,000
Interest on fixed capital	assumed to be 7%	total	3,327,867	0.07	232,951
Total fixed costs					**3,560,817**
Total costs					**−4,919,004**
Gross revenue					**9,514,000**
Net returns					**4,594,996**
Breakeven price	assumption: 10 kg/m				
Above total variable costs					0.14 €[a]
Above total costs					0.52 €[a]
Breakeven yield	assumption: 1.0 €[a]/kg				
Above total variable costs					1.43 kg
Above total costs					5.17 kg

Note: (according to the operating life expectancy of the longline) for the cultivation of consumption mussels at an offshore location (cost and prices in terms of €; base scenario: 10 kg mussel biomass per m longline, eight times yield in four years, market price 1.0 € per kg). Comment: Every year harvest of two plots; no harvest in the first year of the first production cycle due to initial installation.

[a]According to the European Central Bank (ECB) in Frankfurt/Main in Germany (2009) the exchange rate of European Euro [€] to US Dollar [$] ranged from 1.2555 to 1.5090 in 2009 (1 € = 1.2555 US $, resp. 1 € = 1.5090 US $).

Enterprise Budget Analysis

Costs and receipts of four case-scenarios have been calculated. Scenarios analyzed include:

Scenario 1: Production of Consumption Mussels with Investment into a New Vessel. This is the base scenario assuming a four million € investment into a new vessel for farming of mussels for consumption. A general overhaul of the motor is necessary after 10 years and is calculated with 385,000 €. Net returns for an average four year period sum to 4,594,996 € as shown in Table 6.

Scenario 2: Production of Consumption Mussels Using Free Capacities of Existing Mussel Farmers. For this scenario, retrofitting costs for the vessel are about 750,000 €. No land-based facility is included. This leads to net returns of approximately 6,022,000 € in four years, which is 1.3 times higher than in the base scenario (Table 7).

Scenario 3: Production of Seed Mussels with Investment into a New Vessel. Compared to the base scenario, we assume seed mussel cultivation to be less labor intensive. Labor costs are estimated to be 1.2 times lower. Only 40 days of labor are required for offshore work at culture plots, which leads to reduced expenses of fuel. Net returns of 77,668 € will then be achieved (Table 7).

Scenario 4: Production of Seed Mussels Using Free Capacities of Existing Mussel Farmers. This scenario includes retrofitting costs, fewer offshore working

TABLE 7 NPV, IRR and Break-Even-Points for Different Scenarios

Performance / Indicators Scenario	Consumption Mussels, New Vessel + Land Facility	Consumption Mussels, Using Existing Equipment	Seed Mussels, New Vessel + Land Facility	Seed Mussels, Using Existing Equipment
NPV (in €[a])	5,667,073	9,622,937	−4,671,442	559,523
IRR (in %)	14.73	28.11	−2.39	9.63
Net return (in €[a])	4,594,996	6,022,000	77,668	1,505,048
Break-Even-Price (assuming harvest of 10 kg per meter longline, in €[a])	0.52	0.37		
Break-Even-Yield (assuming 1 €[a]/kg consumption mussel, in kg)	5.17	3.67		
Break-Even-Price (assuming harvest of 5 kg/meter longline, in €[a])			0.49	0.34
Break-Even-Yield (assuming 0.5 €[a]/kg seed mussel, in kg)			4.92	3.42

[a]According to the European Central Bank (ECB) in Frankfurt/Main in Germany (2009) the exchange rate of European Euro [€] to US Dollar [$] ranged from 1.2555 to 1.5090 in 2009 (1 € = 1.2555 US $, resp. 1 € = 1.5090 US $).

days and fewer man-months per year as well as no land-based facility. This leads to net returns of approximately 1,505,048 € (Table 7).

Productivity Measures

Break-even yield and break-even price were calculated to estimate the minimum level of biomass production and the minimum price per kg mussel to enable the enterprise to cover costs (see Table 7). Assuming a biomass of 10 kg per meter (consumer mussels) the break-even price is 0.52 € when a new vessel and land facility is taken into calculation. Using existing equipment, a break-even price of 0.37 € results. In the case of seed mussels the break-even price varies between 0.34 and 0.49 €.

Break-even yield for the consumer mussel scenarios lies between 3.67 kg and 5.17 kg per meter longline, respectively, assuming a mussel price of 1 €/kg. In the seed mussel scenario the break-even yields range from 3.42 kg to 4.92 kg.

Actual prices and yields observed at field experiments are higher than the break-even values. This indicates the profitability of both practices, while the consumer mussel production is clearly more above those criterions for economic viability.

Investment Appraisal

Assuming the operating life expectancy of a new vessel to be 20 years, we calculate the NPV of cash flows over 20 years with a discount rate of 7% in the basic model. This rate is chosen according to Liu and Sumaila (2007), who argue that the most frequently used discount rate by Nature Resources Canada is within a range of 5% to 10%. D'Souza et al. (2004) used 7%, 9% and 11%, while Whitmarsh et al. (2006) limits the discount rate to 8%. Due to the sensitivity of the NPV to the discount rate, values ranging from 6% to 9% were used. In the base scenario, the price for one kg of mussels was assumed to be 1.0 €. Net present value amounts to 5,667,073 €, with an IRR of 14.73%. When using existing capacities of mussel farming in Lower Saxony, an investment of about 750,000 € for retrofitting of the vessel at the beginning of the enterprise will be required. All other costs are assumed to be similar to those from the basic scenario. NPV levels around 9,622,937 € and an IRR of 28.11%.

In the case of seed mussels NPV sums to −4,671,442 € if investment into a new vessel and a land facility is necessary, the resulting IRR is −2.39%. If existing equipment can be used NPV is 559,523 € and IRR 9.63%. NPV and IRR for the four scenarios are shown in Table 7.

TABLE 8 Changes of NPV and IRR (in brackets) Due to Key Parameter Variation

	Consumption Mussel with New Vessel and New Land Facility	Consumption Mussel with Existing Capacity	Seed Mussel with New Vessel and New Land Facility	Seed Mussel with Existing Capacity
Biomass harvested				
12.5 kg per m longline	11,410,814 (21.31)	15,366,978 (38.52)		
15 kg per m longline	17,154,556 (27.21)	21,110,419 (48.18)		
5.5 kg per m longline			−3,467,121 (0.38)	1,763,843 (14.99)
Fuel cost				
+10% p.a.	4,489,131 (13.64)	8,444,995 (27.11)	−5,344,551 (n.c.[b])	−113,587 (6.35)
+20% p.a.	801,572 (8.96)	4,757,435 (24.43)	−7,451,728 (n.c.[b])	−2,220,764 (n.c.[b])
Wages				
+3.0% p.a.	5,366,002 (14.44)	9,321,865 (27.80)	−4,945,179 (- 3.39)	285,785 (8.43)
Longline cost increase				
+5% p.a.	2,859,985 (11.65)	6,815,849 (25.02)	−7,478,663 (n.c.[b])	−2,247,698 (n.c.[b])
Price per kg mussel				
0.9 €[a]	3,369,576 (11.81)	7,325,440 (23.66)		
1.1 €[a]	7,964,570 (17.47)	11,920,433 (32.38)		
0.6 €[a]			−2,262,801 (2.87)	2,968,164 (20.13)
Total cost increase				
+5% p.a.	−1,899,456 (2.13)	2,056,407 (15.56)	−9,651,653 (n.c.[b])	−4,420,688 (n.c.[b])
Discount rates				
6%	6,867,422	10,871,396	−4,447,988	831,087
8%	4,611,108	8,522,651	−4,863,591	323,053
9%	3,678,854	7,549,757	−5,029,506	116,498

[a]According to the European Central Bank (ECB) in Frankfurt/Main in Germany (2009) the exchange rate of European Euro [€] to US Dollar [$] ranged from 1.2555 to 1.5090 in 2009 (1 € = 1.2555 US $, resp. 1 € = 1.5090 US $);
[b]means not to calculate.

Economically, the most promising enterprise is the production of consumer mussels if existing equipment can be used. But also in the case of a new vessel and a new land facility profits are likely, since the IRR levels at 14.73%. This should be in most cases higher than the costs of capital. Seed mussel production is obviously only viable if existing equipment can be used.

Sensitivity Analysis

A sensitivity analysis has been carried out to assess the economic feasibility if key parameters of the economic analysis are changing. As the biomass harvested was assumed to be at a low level, the positive impact of a 25% and 50% biomass increase was estimated for consumer mussels as well as an increase of 10% for seed mussel yield. Fuel costs were increased by 10% and 20% per year, wages by 3% per year, longline costs by 5% per year and total costs by 5% per year. Discount rates were varied from 5% over 6% to 8%. The mussel price was changed by ±10% in case of consumer mussels and +20% in case of seed mussels. The results are shown in Table 8. The overall result shows the capacity of the production of consumer mussels with existing equipment to withstand cost increases quite well. In case of a new vessel and new land facility NPV remains positive except for an overall cost increase of 5% per year. All calculated discount rates leave NPV to be positive.

Seed mussel production is much more sensitive to parameter changes. If a new vessel and land facility is necessary, NPV remains negative even if biomass harvested increase by 10%. If existing capacity can be used, the economic viability of this business depends on development of key parameters. An increase of biomass harvested by 10% to 5.5 kg per m longline results in a NPV of 1,763,843 € and an IRR of 14.99%. An increase of the price for seed mussels by 20% amounts to a NPV of 2,968,164 with an IRR of 20.13%. These two cases of parameter changes are the most promising when culturing seed mussels as the IRR is high enough to deal with the risks of the business.

CONCLUSION

Assuming a baseline production of 2,380 tons of consumption mussels per year (2 plots), our results show that the base scenario is clearly beyond the break-even point. Varying parameter values, such as investment costs concerning longlines, new vessels or retrofitting, operating costs like wages and fuel, biomass yield, market price, total cost increases, and different discount rates, show different levels of feasibility. Seed mussel production with

TABLE 9 Additional Advices for Cost Savings

Item		Value
Saving operating costs	–	Diversifying the culture activities: Offer more species with similar cultivation techniques to lower overall labor and production costs. Different species can be cultivated in polyculture[a] or in integrated culture[b] (Chopin et al., 2001). Initial capital budgeting research suggests that recycling the waste of one crop as feed for another can increase profits in a poly- or integrated system (Ridler et al., 2007).
	–	Move harvest and maintenance operations onshore instead of offshore by using new technologies, such as the "easy-to-transport-shellfish-installation" (de Vos, pers. Comm). This reduces expenses for expensive offshore harvesting devices.
Saving investment costs	–	Other methods to slash the cost of expensive harvesting systems could be a husbandry scooter, a multi-use machinery that controls the spat density, reduces predators and fouling, eases harvesting underwater and cleans the collectors before deploying them into sea again (Prins & Schout, 2004).
	–	New spat and grow-out collectors adapted to high energy environments lower detachment (Brenner & Buck, 2010).
Marketing measures	–	Product differentiation: Using ecolabeling as a tool to identify seafood harvested under management regimes that demonstrably prevent over-exploitation of natural stocks (Johnston et al., 2001) and to minimize or avoid negative environmental production externalities (Gudmundsson and Wessels, 2000; Kinnucan et al., 2003). Until today certifiers such as the MSC, has sealed various shellfish products as a *Bio*-Product (MSC, 2007; Anonymous, 2009).
	–	Offshore sites provide a cleaner environment due to having higher oxygen conditions and less urban sewage. Further, the complete absence of macro- and microparasites and bacteria (Buck et al., 2005; Brenner et al., 2007) will lead to a healthy reared quality product, to a "Bio-Mussel."
	–	Further, the innovative technology in producing mussels in close combination with wind turbines, thereby maximizing the use of a seabed area while reducing the pressure on nearshore systems (Michler-Cieluch et al., 2009a), could be an outstanding criterion for sustainability certification.

[a]Cultivation of two or more non-competitive species in the same culture unit;

[b]The by-products from one species (e.g., faeces of fish) are recycled to become inputs for another (e.g., as particulate particle for polychaete). Another example is the recycling from mussel faeces as nutrients for seaweed.

a new vessel and land facility is not profitable, while seed mussel production with existing capacities is profitable under the basic assumptions of parameter values (Table 7). This result is quite sensitive to parameter changes (Table 8), especially since taxes are not included. However, if the price for seed mussel increases due to the lack of seed mussels (Walter & Liebezeit, 2001) this business can remain profitable even with increasing costs. Offshore mussel production for consumption is profitable, but profits are less with a new vessel and a new land facility and higher in the scenarios without a new vessel and a new land facility (Table 7), respectively. The NPV and IRR are large enough that this business can be recommended as long as there are existing capacities (Table 8).

Of course, all businesses can become profitable and respectively more profitable if costs can be reduced and receipts increased. The lack of practical experience of culturing mussels in exposed environments precludes estimating effects of economic risks. Table 9 summarizes some recommendations for cost saving activities as well as possible marketing measures to receive higher prices. Examples regarding financial support would in this case be tailored for the region of Bremerhaven, where various EU programs support regions with high unemployment and ongoing structural weakness (EFF 2007, MEAP 2008). However, every financial support for any region will be site and case specific and will therefore not be discussed here. Nevertheless, similar alternatives to establish a business will be available in other EU-States and beyond.

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