Protocol on
Best Practice Handling and Transportation of Live Mussels
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Development of best practice and new technology for grading, handling, transportation, conditioning and storage of mussels for SMEs in the European mussel industry

Research for the benefit of SMEs

Deliverable 4.1 Report on Best Practice Handling and Transportation of Live Mussels

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<table>
<thead>
<tr>
<th>Dissemination Level</th>
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<tr>
<td>PU</td>
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<td>PP</td>
<td>Restricted to other programme participants (including the Commission Services)</td>
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<td>RE</td>
<td>Restricted to a group specified by the consortium (including the Commission Services)</td>
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<td>CO</td>
<td>Confidential, only for members of the consortium (including the Commission Services)</td>
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Deliverable 4.1 - Report on Best Practice Handling and Transportation of Live Mussels

Project Title

Mussels Alive - Development of best practice and new technology for grading, handling, transportation, conditioning and storage of mussels for SMEs in the European mussel industry

Prepared by (SU):
Sara Barrento
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Alex Keay
# Table of contents

1. Problem definition ................................................. 6
2. Introduction to mussels ........................................... 7
3. Transport of live mussels ........................................ 9
   - Scotland ......................................................... 11
   - Norway ......................................................... 12
   - Ireland ......................................................... 14
   - Systems in use world wide .................................. 15
   - The science perspective .................................... 20
4. Mussels Alive - Simulated transport .............................. 22
5. Regulations and recommendations ................................ 30
6. References ....................................................... 31
Background

The Deliverable 4.1 Report on Best Practice Handling and Transportation of Live Mussels, is an overview of the existing knowledge of the trade chains of mussels produced in Scotland, Ireland and Norway and provides a detailed description of best practice for handling and transportation of blue mussels. This protocol was tailored to participating SME AGs and SMEs.

The methodology used to collect the information for this report was based on available literature, data collected from WP1 and also from personal and phone call interviews to traders of mussels in Scotland, Ireland and Norway.
# Glossary

<table>
<thead>
<tr>
<th><strong>Harvested</strong></th>
<th>Shellfish harvested on the same day and from the same area (if classification is necessary, of the same class).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Batch – Depurated</strong></td>
<td>Shellfish that have been depurated through the same cycle of the same depuration system</td>
</tr>
<tr>
<td><strong>Bivalve molluscs</strong></td>
<td>Any marine or freshwater molluscs of the class Pelecypoda (formerly bivalvia or Lamellibranchia), having a laterally compressed body, a shell consisting of two hinged valves, and gills for respiration. The group includes, among others, clams, cockles, oysters and mussels.</td>
</tr>
<tr>
<td><strong>Classification of bivalve mollusc harvesting areas</strong></td>
<td>A system for grading harvesting areas based on levels of bacterial indicator organisms in the surrounding seawater (using faecal coliforms in the US) or the shellfish themselves (using <em>Escherichia coli</em> within the EU).</td>
</tr>
<tr>
<td><strong>Clean seawater</strong></td>
<td>Seawater from any source where harmful microbiological contamination, substances and/or toxic plankton are not present in such quantities as may adversely affect the health quality of bivalve molluscs or to impair their taste</td>
</tr>
<tr>
<td><strong>Coliform</strong></td>
<td>Gram negative, facultatively anaerobic rod-shaped bacteria which ferment lactose to produce acid and gas at 37 °C. Members of this group normally inhabit the intestine of warm-blooded animals but may also be found in the environment (e.g. on plant material and soil).</td>
</tr>
<tr>
<td><strong>Conditioning</strong></td>
<td>The storage of live bivalve molluscs, whose quality does not indicate the need for relaying or treatment in a purification plant, in tanks or any other installation containing clean sea water or in natural sites to remove sand, mud or slime and improve product acceptability</td>
</tr>
<tr>
<td><strong>Depuration cycle</strong></td>
<td>The depuration process from the point at which the shellfish are immersed in the seawater and all of the conditions for depuration process are in the correct range until the time when depuration is ended, e.g. by draining the tanks. If conditions go out of range then the cycle must be identified as starting again for the purposes of the depuration period.</td>
</tr>
<tr>
<td><strong>Depuration centre</strong></td>
<td>Any approved establishment for the depuration of live bivalve molluscs</td>
</tr>
<tr>
<td><strong>Escherichia coli</strong></td>
<td>A species of bacterium specifically associated with the intestines of warm-blooded animals and birds</td>
</tr>
<tr>
<td><strong>Heat shocking</strong></td>
<td>The process of subjecting bivalve molluscs in the shell to any form of heat treatment, such as steam, hot water, or dry heat for a short period of time, to facilitate rapid removal of meat from the shell for the purpose of shucking</td>
</tr>
<tr>
<td><strong>Relay area</strong></td>
<td>Any sea, estuarine or lagoon area with boundaries clearly marked and indicated by buoys, posts or any other fixed means, and used exclusively for the natural purification of live bivalve molluscs.</td>
</tr>
<tr>
<td><strong>Relaying</strong></td>
<td>The removal of bivalve molluscs from microbiologically contaminated growing area to an acceptable growing or holding area under the supervision of the agency having jurisdiction and holding them there for the time necessary for the reduction of contamination to an acceptable level for human consumption (Codex Alimentarius Code of Practice).</td>
</tr>
</tbody>
</table>
1. Problem definition

Transporting live mussels

Bivalve species like oysters, mussels, manila and hard shell clams can survive for extended periods out of water and can be traded for human consumption as live animals.

The primary aim of capturing, holding and transporting live mussels is to deliver them to market in the best possible condition. Mussels will be exposed to some level of stress during all or part of the trade chain.

Stress can be defined as any factor (either external or internal) causing a physiological disturbance to the mussels. In the live mussel industry these factors include capture, de-clumping, fluctuating temperatures, sunlight and other bright lights, wind or drafts, handling and physical damage, poor water quality during holding, conditioning and purification. Mussels are generally able to recover from such stresses, however if any or a combination of those stresses are sufficiently intense, then poor quality (broken shells, gaping, unpleasant smell) or dead mussels will result. Thus, transport systems need to ensure mussels are held in conditions that keep stress to a minimum.

The design of transport systems is governed by a number of factors, with economics being a major driving factor. Systems also need to be practical to use and manage, and designed to suit the biological requirements of the animal. For mussels there is now a range of biological information that can be practically used in the design of transport systems. How the information is adopted will depend on the harvesting origin of mussels (cold water, temperate waters), transport duration and reception infrastructures.

This guide provides information to the mussel industry on transport of live mussels, focussing on the physiological requirements of mussels and methods of ensuring optimal conditions. Further experiments to optimize the best transport and recovery temperatures might be needed. Operators must be aware that for the same problem different solutions can arise and different procedures might be needed throughout the year according to temperature changes. Traceability and a narrower trade chain would also assist the technical procedures required to achieve a better transport and standardized handling and transport practices.
2. Introduction to mussels

Life in seawater

Mussels are invertebrate molluscs including familiar forms such as clams, oysters, squids, octopus and snails. Mussels dominate the intertidal region (Figure 1) in temperate seas of the northern and southern hemispheres; they can form extensive beds dominating the rock surface, strips or patches. Mussels living in the intertidal zone must be able to survive exposure to the air (desiccation), abrasion action of waves and ice, discontinuous availability of food, large fluctuations in temperature, and sometimes exposure to fresh water from the rain and seeping groundwater. Competition and predation by starfish, dog whelks, shore crabs and various birds are also factors important in determining its distribution. Starvation is also a risk when the tide is out, since most intertidal animals feed only when they are submerged. The length of time that organisms are exposed to the air depends on the local tidal range and on where on the shore they are located. On the other hand mussels cultured in long lines and rafts are submerged continuously and do not face the same challenges.

Figure 1. Intertidal zone.

Animals have evolved different strategies to cope with challenges of life according to their habitats; Mussels that live in the intertidal zone have increased thermal resistance, reduced evaporation when exposed to air as they normally are trained to close their valves and thus exhibit a longer shelf-life than those that are submerged continuously.
# Blue Mussel Quick Fact Sheet

## Distribution
Occurs from the White Sea, south to southern France in the N.E. Atlantic. In the W. Atlantic it extends from the Canadian Maritimes south to North Carolina. It occurs on the coasts of Chile, Argentina, the Falkland Islands and the Kerguelen Isles.

## Habitat Preferences

### Physiographic preferences
- Open coast
- Strait / sound
- Sea loch
- Ria / Voe
- Estuary
- Enclosed coast / Embayment

### Biological zone preferences
- Lower Eulittoral
- Mid Eulittoral
- Sublittoral Fringe
- Upper Eulittoral
- Upper Infra littoral

### Substratum / habitat preferences
- Artificial (e.g. metal, wood, concrete)
- Bedrock
- Biogenic reef
- Caves
- Crevices / fissures
- Large to very large boulders
- Mixed
- Muddy gravel
- Muddy sand
- Rockpools
- Sandy mud
- Small boulders
- Under boulders

### Tidal strength preferences
- Moderately Strong (1-3 kn)
- Strong (3-6 kn)
- Weak (<1 kn)

### Wave exposure preferences
- Exposed
- Moderately Exposed
- Sheltered
- Very Exposed
- Very Sheltered

### Salinity preferences
- Full (30-40 ‰)
- Reduced (18-30 ‰)
- Variable (18-40 ‰)

### Temperature preferences
- From 0 to 20 °C

### Oxygen preferences
- Above 60 %

### Preferred particle concentration
- $5 \times 10^5$ to $> 800 \times 10^5$ cells/mL

### Particle size
- $> 2 \, \mu m$ to $100 \, \mu m$

### Light preferences
- Mussels are more active during the night

### Depth range
- Intertidal to approximately 5m

## Reproduction

### Reproductive type
- Having separate sexes

### Reproductive frequency
- Breeds every year over an extended or drawn out period

### Age at maturity
- 1 to 2 years

### Generation time
- 1 to 2 years

### Fecundity (no. of eggs)
- >1,000,000 up to 20,000,000

### Time of first gamete
- April

### Time of last gamete
- September

### Larval settling time
- 1 to 6 months
3. Transport of live mussels

The industry perspective: Scotland, Ireland and Norway

The trade chain is different in Norway, Scotland and Ireland. To have a better understanding of the different aspects of the three countries, questionnaires were developed and disseminated in these three countries. Transport occurs at different stages of the trade chain. The following diagram is a brief summary of the trade chain which has already been approached in previous deliverables and illustrates where transport takes place during the trade of live mussels. The short distance transport corresponds to transfers that take place in a matter of few minutes, for instance from the harvesting site to the barge, or to the shore where the dispatch or depuration centres are usually located.

Whereas the medium to long distance transport corresponds to transfers that can take a few hours to up to 3 days. In total 6 Scottish companies, 3 Norwegian companies and 4 Irish companies participated in this questionnaire. One of the driving factors that makes transport and transport units different among companies and in the same company is the client requirements (quantity; graded vs. non graded; mussels to be sold fresh or processed).

To better understand the medium to long distance transport process, the following table shows a brief summary of transport units and type of vehicles used by the three countries.

![Diagram summarizing the trade chain of live mussels and deliverables reports developed.](image-url)
Table 1 Summary of the transport units and vehicle used by the different companies in Scotland, Norway and Ireland; n – number of companies interviewed that use the transport unit or vehicle specified in each row.

<table>
<thead>
<tr>
<th>Transport Units</th>
<th>Scotland (n=6)</th>
<th>Norway (n=4)</th>
<th>Ireland (n=3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg net</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2 kg -10 kg net bags</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Cardbox 15 kg</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20 to 25 kg bags, each with 4 or 5 nets (5 kg each)</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Box (25 kg)</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bins (250-300kg)</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bags (500-800 kg)</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light good vehicle (closed chilled van at 4 °C)</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Lorry chilled at 0-4 °C</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Lorry chilled at 3-5°C</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

Details regarding each country are given in the following pages.
Systems in use: Scotland

The questionnaires were completed through personal interviews made during the Association of Scottish Shellfish Growers annual meeting which took place in Oban between the 3rd and 5th of October, 2011. The six companies that participated in the questionnaire represent 25% of the total production (tonnes/year) in Scotland, (that is 7199 tonnes in 2010 [1]). In general companies with annual production above 150 tonnes, believe that ice is crucial during transport.

One of the companies specializes in providing mussels during the summer months as they found a market opportunity between April and October. During this season, live mussels have a high demand but it is also difficult to supply the live market, as mussels are usually spawning or sites might be class B or even closed due to biotoxins. This company supplies mussels to restaurants in the UK and to the Scottish Shellfish Marketing Group (SSMG). According to the manager of this company the crucial issue is to add ice as quick as possible either to 5 kg net bags, which are transported to restaurants in bins each with 50 bags (250 kg) covered with ice or to bulk bags (800 kg) that are transported to the SSMG.

The reasoning behind this practice, according to the manager, is to prevent mussels from gaping. In the 800 kg bags bottom mussels cannot open due to the weight anyway, but top mussels must be kept on ice.

"Ice and keeping the cool chain is essential to keep mussels alive especially during summer months."

Another producer that depurates mussels also mentioned that ice is essential. In this case after depuration, mussels are graded and packed either in 5 kg net bags or in 15 kg polystyrene or card boxes. The net bags are usually transported in bins each containing 60 net bags (300 kg total) and the ice is added in between the several layers of bags. The 15 kg boxes are also iced.

Mussel can also be exported to France usually in 800 kg bags in Curtainsiders chilled at 4 °C. The duration of transport varies depending on distance; transport to nearby restaurants can take only 2 h but across the UK it can also take up to 24 h. Mussels that are transferred to the SSMG take usually between 6 to 12 h, whereas export to France can take up to 3 days.

Table 2: Transport duration depending on the client. In the second column n means the total number of companies that have a commercial relation with the clients stated in each row.

<table>
<thead>
<tr>
<th>Client</th>
<th>n</th>
<th>Transport duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scottish Shellfish Marketing Group</td>
<td>3</td>
<td>6 - 12 h</td>
</tr>
<tr>
<td>Restaurants in UK</td>
<td>2</td>
<td>2 – 24 h</td>
</tr>
<tr>
<td>France depuration/dispatch centre</td>
<td>3</td>
<td>3 days</td>
</tr>
</tbody>
</table>

In general mussel producers have no idea of mortality after transport because there is no feedback from the client. One of the interviewees commented that farmers may never realize that the system is not working just because they are not kept up to date.
**Systems in use: Norway**

The questionnaires were completed through person to person and phone interviews made during August/September 2011, in Norway. The three companies that participated in the questionnaire represent 74 % of the total production (tonnes/year) in Norway, (that is 1900 tonnes in 2008).

All the three companies interviewed transport mussels in 1 kg net bags. Usually ten net bags are placed in boxes with ice, in a proportion of 2-3 kg of ice per box, (i.e. 10 kg of mussels). One company also mentioned that 1 kg mussels can be packed in modified atmosphere packaging (MAP), and 4-8 units are stacked in a card box. Usually mussels are transported from the dispatch centre to a central distribution centre and then to wholesalers followed by supermarket platform and restaurants. All three companies hire a transport company. Mussels are usually transported in lorries with closed rears that can carry a cargo between 12 to 24 tonnes. The air temperature is set to be between 0 to 4°C. In the following Table 3 is a summary concerning the transport to wholesalers.

<table>
<thead>
<tr>
<th>Central distribution centre</th>
<th>Trondheim</th>
<th>Oslo region</th>
<th>Bergen</th>
<th>Moscow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average transport load</td>
<td>2.5 - 4.9 tonnes</td>
<td>2 tonnes</td>
<td>depends</td>
<td>depends</td>
</tr>
<tr>
<td>Transport duration to the destination</td>
<td>2h</td>
<td>14h</td>
<td>38h</td>
<td>72h</td>
</tr>
<tr>
<td>Mortality after transport</td>
<td>0 &lt; 1%</td>
<td>0 &lt; 1%</td>
<td>0 %</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Presence of unpleasant smell after transport</td>
<td>Never</td>
<td>Occasionally</td>
<td>Occasionally</td>
<td>Never</td>
</tr>
</tbody>
</table>

One of the companies managers mentioned that smell related to transport is not relevant and does not occur, as long as the cooling system on the truck is working. If a smell occurs it is most probably in modified atmosphere packed mussels. However another manager thinks that the smell in fresh mussels can occur and he suspects that it might also be due to fouling organisms that apparently can promote a sweet smell during transport. Sometimes it is too hot in the lorry and the ice in the 10 kg boxes melts. The temperature regime upwards through the chain (operators, supermarket, etc.) is not well known. There can also be delays due to bad weather and accidents, which again can compromise the uninterrupted cooling throughout the supply chain.

The Norwegian managers realize that keeping the cool chain is the major critical point, especially during the summer months.
One solution to this problem is to keep operators and clients well informed and aware of the importance of temperature control. In this regard they understand that training is of crucial importance.

Packaging was also pointed out as a crucial issue; mussels too fouled cannot be packed in modified atmosphere, because they puncture the package. One manager mentioned that mussels spawn in the dispatch centre, this is very common and it can happen daily for 2 months or more (May, June, first half of July).

Sometimes spawning occurs after packing, which is a problem in MAP. During this time of the year this company tries to induce spawning by double washing the mussels. In another company they just discard spawning mussels.

There is also some concern about what works best: a closed box or an open one, the best ratio of mussel to ice, and the amount of mussels per box, considering the space, air available.
Four Irish companies participated in this questionnaire, 3 companies sent the questionnaire by mail, and one was interviewed during the IFA aquaculture annual meeting which took place on the 22nd of October, 2011 in Kinsale, Ireland.

Two of the interviewed companies are relatively small with an annual production between 45 and 100 tonnes, and one only sells 20 or 25% of their total production (50 to 100 tonnes) as fresh product. These companies only supply the internal market, mainly Irish restaurants. In this case the mussels are directly transported from the dispatch centre to the restaurants, which last between 3 to 5 hours. Mussels are usually packed in 2 to 10 kg net bags and up to 400 kg in total are transported in a light vehicle van with a cooler system set between 3-5°C.

The other two companies that export mussels have an annual production between 600 and 1000 tonnes. One of the companies does not sell live mussels during the summer, because of spawning and lack of condition of mussels. Usually 5 to 25 tonnes of mussels are harvested per day and the mussels that are sold live are first trained in 25 kg mesh bags and then dispatched in 1 tonne pallets in a refrigerated lorry. Transportation to France usually takes 2 to 3 days.

One company does not harvest mussels between late January and early May, and then again in August and September, basically because of spawning or biotoxin outbreaks. This company is a depurator, dispatch and processing centre combined in one. From harvesting site to the depuration/dispatch/processing centre mussels are transported in 1-5 kg tubs or in bags with 800 to 1 tonne mussels. They are loaded onto refrigerated trucks. Then mussels can be either depurated or processed. The packing units usually used are 1, 5 and 25 kg net bags or modified atmosphere packing (MAP), trays of 1 to 5 kg. The MAP are sent in a refrigerated truck either to France or Ireland. Whereas the net bags are sent to France.

One of the mussel producers complained that in Ireland the truck transport to the UK or continental Europe is limited. Also wholesalers are not up to speed with quality and de-bearding prior to sale.

Table 4 Transport duration depending on the client. In the second column n means the total number of companies that have a commercial relation with the clients stated in each row.

<table>
<thead>
<tr>
<th>Client</th>
<th>n</th>
<th>Transport duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restaurants in Ireland</td>
<td>4</td>
<td>2-5 h</td>
</tr>
<tr>
<td>France depuration/dispatch centre</td>
<td>2</td>
<td>2-3 days</td>
</tr>
</tbody>
</table>
Transport of live mussels

The industry perspective: systems in use worldwide

Spain

Aurelio Silva Abalo, S.A. is a depuration centre located in Illa de Arosa (North of Spain).

- Mussels are harvested in Galicia and transported to the depuration centre through a conveyor belt.

- Once in the depuration centre mussels are depurated for 24 h before being packed in either wooden boxes with ice (5 to 6 kg) or net bags of different sizes (5, 10 and 15 kg).

- Mussels are always transported on ice, and this company has invested in its own ice production.

Figure 5 Aurelio Silva Abalo, S.A. mussel transport at different steps of the trade chain (Pictures taken from http://www.aureliosilva.eu/)
Kinkawooka Shellfish is an owner-operated company located in Port Lincoln, South Australia. Mussels, *Mytilus galloprovincialis* are harvested, de-clumped and graded at sea and kept at a constant temperature in bags with ice. These bags are transported from the vessel to the factory inside chilled bins thus maximizing shelf life. In this area there is no need to depurate mussels and therefore mussels arriving at the factory are de-byssed, scrubbed and immediately vacuum packed.

The mussels are available in 2 grades:

- **Large:** 85 mm + shell length with a meat to shell ratio 38 %;
- **Standard:** 65-85 mm shell length with a meat to shell ratio of 36-40 %.

They are packed in a reduced atmosphere 1kg VAC bag, chilled and then placed in a 12 kg styrene esky with ice.

Systems in use worldwide

Canada

Whereas in Australia and in New Zealand the bag system is used to transport mussels, in Canada tote pan and vats (see picture below) are used covered with ice to maintain temperature low. There are both advantages and disadvantages to using either vats or totes. Vats offer a better control over quality affecting criteria – temperature and handling stress. Vats are insulating and require less ice to maintain temperature. Therefore cost saving on ice purchases may be realized. Moreover, adopting vats in all aspects of mussel production is HACCP and quality friendly [2].

Advantages
- Small and stackable for easy transport
- Relatively easy to move about when full
- Cheap

Disadvantages
- No insulating value by themselves, requires more ice to maintain temperature
- Small volume, must have many on hand for large harvests
- Large harvest requires much physical labour

Advantages
- Insulating value keeps product cold
- Large volumes can be transported, with less handling and less stress and a higher quality
- Stackable

Disadvantages
- Potential infrastructure limit use, inadequate boat/ barge size, room limitations, low ceilings or small spaces at dispatch centre
- Potential crushing of mussel if thin shelled or filled improperly
- Cost
The slurry ice technology

Whether mussels come from Australia, Canada or Spain, there is one practice that is common to all these markets, that is the utilization of ice to store and transport mussels. Recently in Canada, the company Prince Edward Aqua Farms Inc. started using slurry ice from Sunwell, Deepchill™ System to pack the mussels and ship them to markets across North America.

Aquatic food products in general have traditionally been preserved by packing in ice, either in pounds or boxes, which is a time-consuming strategy [3]. But slurry ice is an efficient alternative to ice flakes.

According to Jerry Bidgood, General Manager of Prince Edward Aqua Farms (2006) “The flake ice system required a lot of manual labour; ice had to be shovelled into every box and vat. Ice on the bottom, middle and top. This was OK but it melted quickly and didn’t cool all the product quickly. The slurry ice system gave us an automated method for icing that got in between every mussel in every bag, ensuring fast cooling of the entire product. The mussels are cooled down to just above 0°C”.

Ice slurry is a homogenous mixture of small ice particles and carrier liquid. The liquid can be either pure freshwater, saltwater or a binary solution consisting of water and a freezing point depressant. Ethanol, ethylene glycol and propylene glycol are the most commonly used freezing point depressants in industry [5]. Slurry Ice is also known as liquid ice, slush ice, flow ice, fluid ice, or by a wide range of trade or brand names.

1. Slurry Ice can be pumped through regular hoses or pipes, so no more shovelling and hauling bins or tubs with ice cubes or flakes; thereby improving hygienic handling, and may be combined with other agents, such as ozone, to achieve an antiseptic surface effect [6-8];
2. Slurry Ice surrounds the mussels completely, leaving no air pockets, and therefore capable to extract heat better, faster and more efficiently[3];
3. Slurry Ice is soft and has no jagged or sharp edges, thus preventing injuries or damages to the product-to-be-cooled[3];
The Prince Edward Aqua Farms process is as follows:

After harvesting, mussels arrive in insulated containers. They are inspected then go to processing to be cleaned and graded.

They are then placed into wet storage for 24 h to ensure all sand and grit is cleaned out. The wet storage temperature is supplied and maintained by pure ocean water in the winter, and by salt water wells in the summer.

As orders arrive, mussels are taken from wet storage and go through the cleaning, de-bearding and final hand grading.

Finally, mussels are packed by weight in mesh bags from 1 kg to 11 kg and placed in containers weighing from 4.5 to 450 kg, according to the customers’ requests. Then they go to the cool room to be iced (Figure 8).

The icing system uses seawater to produce as much as five tons of dry ice, or almost 10 tons of slurry ice per day. The slurry ice with an ice fraction of 50-60% (ice percentage in the deepchill™) is automatically pumped to four separate locations at the facility. At the first two locations the slurry ice is discharged into 1 ton bulk containers holding 360-400 kg of mussels packed in the mesh bags.

A third discharge location is found in a chill room and is used for packing mussels in waxed boxes of 22, 11 or 4.5 kg configurations. Mesh bags of mussels are placed into the boxes and slurry ice is discharged over and around the bags. Again, the slurry ice flows into every space and crevice to provide ultimate contact cooling.

The final discharge station is also located in the chill room, over 150 ft (45m) away from the deepchill™ generators. It is used for packing both, the bulk containers and waxed boxes, as well as a re-icing station to maintain mussels that are packed on non-shipping days.

Slurry ice lasts longer because it can be packed more densely making it possible to get more ice into the boxes. This company claims that mussels in this type of ice have 10 to 12 days shelf life whereas with other types of ice the shelf life is only seven days.
Transport of live mussels

The science perspective

There are four possible storage conditions for live mussels: ice, no ice (chilled air) and seawater at ambient or cooler temperatures. However only two are feasible in the context of transport and that is ice or no ice.

The use of ice prolongs the average shelf life of the blue mussel, *M. edulis* in comparison to mussels held in ambient air temperatures without ice or held in chilled rooms without ice [9, 10]. As well, holding mussels under melting ice, as opposed to just in or on ice, can further increase shelf life by more than 5 days [9-11].

Recent results obtained by Harding *et al.* (2004) [12] suggest that producers should use ice as part of their storage practice to reduce stress, increase quality and extend the value of their product. According to these authors, late autumn (December) through to the spring (May) of the year is when mussels are in the best physiological condition, and can better cope with the stress of handling, processing, and storage. It was shown that the benefit of using ice is more evident during summer months, when mussels are more fragile (spawning season).

In Canada trials were carried out with mussels uncovered, covered but without ice, and iced [2].

Mussels left uncovered showed core temperatures in the tote pan to either stay similar to ambient temperature or increased and fluctuated; temperatures were never below 15°C.

Mussels covered by a tarp showed temperatures similar to ambient harvest temperature, increased or fluctuated; temperatures were never below 15°C. Mussels that were iced had core temperatures drop dramatically to 1°C within 30 minutes of harvest.
Adding ice to mussels during harvesting effectively chills the product quickly.

Also, holding mussels under melting ice, as opposed to just in or on ice, can further increase shelf life by more than 5 days \([10, 11]\).

Leaving mussels uncovered and exposed to the wind and hot sun will not only trigger spawning during summer months but it will also promote desiccation. It has been reported that mussels begin to suffer significant mortality after 20\% or more of body weight lost through desiccation. The absolute loss of weight as water is greater in larger than in smaller mussels, but the percentage loss is greater in the smaller individuals. In this respect it has been suggested that wind is a major factor in accelerating water loss, and an important cause of mortality \([13]\).
4. MusselsAlive Trial

Swansea University

In March 2011 mussels were sampled to assess their general condition after several critical steps post harvesting and after different transport conditions. The parameters measured were: gaping, survival, weight loss and ammonia content in the blood serum and water mantle cavity. Temperature during transport was also registered.

The sampling took place in Scotland, at the depuration site in Achnacloich, and at the Scottish Association for Marine Science, (SAMS) located in Oban. Mussels were then transported to Swansea University in Wales, where they were sampled after transport and after 24 h re-watering (Figure 11).

In Scotland mussels were sampled immediately after grading. The mussels were then separated into 48 bags of approximately 5 kg. Bags 1-24 were placed into a vat for depuration for 48 hours (7°C), the facility was located in Achnacloich. The other half were stored at 8°C in a controlled temperature room at the Scottish Association for Marine Science about 20 minutes away from Achnacloich. After about 48 h the mussels that were not depurated were picked up from cold storage from SAMS and brought to Achnacloich for sampling with the mussels that were depurated.

The bags were put into 8 polystyrene boxes of the same size (6 bags in each box) alternatively with and without ice, and with and without a lid, as shown in figure 12. The boxes without a lid were stored in the van for transportation on the top of the other boxes (to avoid being covered over as if covered by a lid). The mussels were then driven to Swansea in a refrigerated van with temperature conditions set at 7°C.
MusselsAlive Trial

After 22 h transport mussels were sampled once again at Swansea University, then bags were put in a seawater tank system to be flushed during 24 h. After this, mussels were sampled again. In summary, there were four sampling points, after grading, after depuration or storage on ice (48 h), after 22 h transport and finally after 24 h re-watering. At each stage mussels were sampled to collect either blood and water mantle cavity to measure ammonia and to assess mortality and gaping. Additionally bags were weighted before and after 22 h of transport. The general experimental set up is shown in the Figure 12.

Figure 12 Experimental set up. ⚫ - blood samples; ⛔️ - water mantle cavity samples; ☑️ - temperature loggers. M - mortality.
MusselsAlive Trial

Results

This experiment has two elements. The first provides a comparison of the consequences of re-watering, in this case via depuration, in relation to dry storage on ice, immediately after grading. The second part assesses the added effect of different transport conditions as a consequence of the impact of depuration or dry storage.

1. Depuration vs. dry storage on ice

Mortality results indicate that re-watering might have a beneficial effect, as only 2% of mussels died after depuration comparatively to the 6% obtained after dry storage (Figure 13). Also there was no gaping after depuration but after 48 h of dry storage on ice 1% of mussels were gaping.

Ammonia concentration in the serum was higher after 48 h dry storage on ice than after depuration (Figure 14).

2. Different transport conditions and re-watering

2.1. Temperature in the transport boxes

The temperature in each box was registered with loggers. This is similar to the procedure used in Canada and described on page 19. The ambient temperature in the box with ice and lid was maintained at 1°C during the 22 h of simulated transport whereas, without the lid, the temperature which was initially low (2°C), increased during transport up to 6°C (Figure 15). Without ice but with the lid on the temperature was kept between 6 and 7°C.

Previously it was concluded that adding ice to mussels during harvesting effectively chills the product quickly [2]. In this trial it is also concluded that mussels kept in a polystyrene box with ice and a lid are chilled quickly and most importantly, they are kept at low temperatures (1°C) during 22 h of transport.
Figure 15 Temperature during different transport conditions. Blue line indicates temperature in each box; A – Ice & Lid; B – Ice & No Lid; C - No Ice Lid; the red dotted line indicates the temperature in the van, slightly above 9°C.
**MusselsAlive Trial**

### 2.2. Mortality

After transport the mortality was not checked for all 8 boxes (see Figure 12), but it was between 5% for depurated mussels transported with ice and lid, and 4% for the remaining treatments. This result is not conclusive, though, as there is not enough information for all treatments.

After 24 h re-watering mussels that hadn’t been depurated, and therefore spent 60 h out of water had the highest mortalities especially those in boxes without a lid. In general, even comparing mussels that were depurated, and only spent 22 h out of water, those in boxes without a lid had a slightly higher mortality (Figure 16).

![Figure 16 Mortality after re-watering considering all transport treatments: mussels in a box with ice & lid; with ice but no lid; without ice but with the lid and without both ice and lid.](image1)

![Figure 17 Re-watering of depurated mussels (Picture courtesy Adam Powell).](image2)

![Figure 18 Re-watering of non depurated mussels Picture courtesy Adam Powell).](image3)
2.3. Weight loss

It is general knowledge that during transport out of the water mussels lose water and thus weight. During the interviews, one mussel farmer who depurates all mussels mentioned that in his company mussels are packed in net bags (5 kg) but with an excess of weight, usually 5.8 kg per bag but after transport there is only 5.3 kg left (~8% loss).

During the trial conducted at Swansea University, bags were weighed before and after transport and even though there is a great variability between bags, mussels lost weight (Figure 19). In general non depurated mussels lost more weight than depurated mussels. Probably this difference would be even more evident, if mussels had been weighed before being stored on ice for 48 h and then after the 22 h in different boxes. Because at this stage, non depurated mussels had been out of water for 60 hours. Whereas depurated mussels had only been out of water for 22 h.

The results also indicate that there is no real difference between treatments (boxes) in the non depurated mussels, with an average weight loss between 11.8 and 14.2%. Probably because these mussels had previously been on ice for 48 h. However, there is a tendency for depurated mussel to lose more weight in the box without ice and lid (7.4%) than in the box with ice and lid (2.7%). The results obtained in the box with ice but without lid (3.8 ± 2.3%) are slightly lower than the number reported by the mussel farmer (8%), with mussels transported under the same conditions.

Figure 19 Average weight loss (%) of mussels after transport minus STDV. Two types of mussels were transported: depurated during 48 h and stored on ice during 48 h. Transport treatments: 1) box with ice and a lid (Ice&Lid); 2) box with ice but no lid (Ice No Lid); 3) box without ice but with a lid (No Ice Lid) and 4) box without ice and without a lid No Ice & No Lid.
2.4 Serum Ammonia

Measurements of ammonia in blood serum provide a rapid, quantitative index of the physiological state of *Mytilus edulis* [14]. Figure 20 depicts the ammonia content in the serum of mussels during several critical steps of the trade chain.

Results indicate that in general ammonia increases during emersion and that mussels recover if re-watered.

After 48 h depuration in immersed conditions, ammonia content in the serum is similar to just after grading, but after the same period on ice, the ammonia content increases. After 22 h on ice with a lid, mussels that have been depurated have a similar ammonia content as mussels that were stored under the same conditions for 48 h immediately after grading. This could indicate that a maximum threshold is reached for mussels on ice after 24 h. However, if mussels are kept on ice for more than 48 h, in this case 60 h, the ammonia content can increase further and reach extreme high values (> 20 µg/mL), but the variability also increases. Without ice but with a lid the ammonia content does not reach the maximum values that are reached with ice, especially in the depurated mussels.

Once mussels are re-watered after dry storage, with or without ice, for 22 or 60 h, they all recover, and ammonia levels decrease to values similar to the initial stage, that is immediately after grading. This means that re-immersion is an effective recovery step.

![Figure 20](image-url)

Figure 20 Average ammonia concentration ±STDV in the serum of mussels during the 84 h experiment, that is immediately after grading, after 48 h depuration and after the same period on ice. These mussels were then transferred to transport boxes under different conditions during more 22 h, at this stage the experiment was running for 60 h, and then mussels were re-watered during 24 h.
MusselsAlive Trial

Previous studies reported that a 24h re-immersion process of the mussels following any of the other processing activities (e.g. washing, de-clumping and grading) reduced the initial stressful impact of the processing activity [12]. Survival of mussels had already been reported to increase by over 30% with a 12 h re-immersion period and 50% after a 48h re-immersion period [9] [15]. It has also been found that the condition and quality of mussels can be improved with re-immersion as liquor is recovered, byssal damage is repaired, and trapped mud can be filtered out of the mussels [9].

In general it can be concluded that:

1. the duration of dry storage has a cumulative effect on mortality and ammonia build-up in the blood.
2. mussels in polystyrene boxes with ice and lid are chilled quickly and most importantly, they are kept at low temperatures (1°C) during 22 h of transport. This means that during this period there are no temperature variations, thus the cool chain is maintained.
3. Mussels in boxes with a lid suffered less mortality after re-watering than mussels in boxes without a lid and in general the weight loss during transport was more variable.
4. Re-watering has a beneficial effect after grading and after transport.

Suggestions for future research

Even though re-watering after de-byssing was not tested in this trial, there is evidence that this is also most beneficial and recommended [12].

Duration of re-watering should be further investigated, because it might be that 12 h is enough. On the other hand re-watering duration might be dependent on the type of processing activities that the mussels have been through.

Storage on slurry ice should be further investigated.

General Recommendations

Coordination is key to avoid delays and breakdown in product quality. Develop and maintain a harvest plan that includes transporting product pre and post harvest.

Containers must not be overloaded

Use care in moving or unloading containers to prevent shock stress

Minimize product exposure to sunlight, wind, rain or snow.

Record keeping is essential. Check and record temperatures of product before loading onto truck. Check and record temperature at the time of unloading at the centre. If mussels are being held for an extended period of time, continue to monitor and record temperatures on a regular basis.

In the following page is a summary of the EU regulations and Codex Alimentarius recommendations
# 5. Regulations and recommendations

## General

- The product should be dispatched in the sequence of the lot numbers (*).
- The cold chain is not to be interrupted (G).
  
  However, limited periods outside temperature control are permitted, to accommodate the practicalities of handling during preparation, transport, storage, display and service of food, provided that it does not result in a risk to health (G).
- Live mussels must be kept at a temperature that does not adversely affect food safety or their viability (B).
- Temperature should be maintained during distribution to control microbial growth(*).

## Transport Vehicle

- Means of transport must permit adequate drainage, be equipped to ensure the best survival conditions possible and provide efficient protection against contamination (A).
- The design and layout of rooms contained for means of transport should permit good food hygiene practices, including protection against contamination between and during operations. In particular (C):
  - floor surfaces and wall surfaces - maintained in a sound condition and be easy to clean (C);
  - ceiling or roof, interior surface of the roof and overhead fixtures are to be constructed and finished so as to prevent the accumulation of dirt and to reduce condensation, the growth of undesirable mould and the shedding of particles (C);
  - walls, floors and ceilings, where appropriate, are made of a suitable corrosion-resistant material with smooth, non-absorbent surfaces. Floors should be adequately drained (*).
- Vehicles should be designed and constructed where appropriate:
  - with chilling equipment to maintain chilled shellfish during transportation to a temperature as close as possible to 0 °C;
  - to provide the fish or shellfish with protection against contamination, exposure;
  - to avoid extreme temperatures and the drying effects of the sun or wind.

## Containers

- Must be kept clean and maintained in good repair and condition to protect foodstuffs from contamination and are, where necessary, to be designed and constructed to permit adequate cleaning and/or disinfection (D).
- Should provide sufficient protection of the bivalve molluscs against damage to the shells from shocks.
- Are to be placed and protected as to minimise the risk of contamination (E).
- The bivalve molluscs should not be transported with other products that might contaminate them (*).
- Capable of maintaining foodstuffs at appropriate temperatures and allow those temperatures to be monitored (F).
- Bivalve molluscs intended for human consumption should only be distributed in closed packaging (*).

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B) 853/2004, Annex III, Section VII, Chap VIII, 1  
C) 852/2004, Annex II, Chap II, 1  
D) 852/2004, Annex II, Chap IV, 1  
E) 852/2004, Annex II, Chap IV, 6  
F) 852/2004, Annex II, Chap IV, 7  

(*) Codex Alimentarius
6. References


