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Deliverable Report 3.1 : Protocol on Best Practice Handling & storage of crustacean commodity at landing/recovery station.

Edible crab (*Cancer pagurus)*

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

This deliverable consists of 3 reports

3.1 a. Protocol on Best Practice, handling & storage of crustacean commodity at landing/recovery station and transportation.

3.1 b. Grading on meat content, development of Boat Mounted NIR Scanner.

3.1 c: Rapid non-destructive determination of edible meat content in crabs (Cancer pagurus) by NIR imaging spectroscopy

Deliverable 3.1 a

Protocol on Best Practice handling & storage of crustacean commodity at landing/recovery station and transportation

Edible crab

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Preface

CrustaSea is a collective EU project focuses on improving the infrastructure of our crustacean fishery sector initiating the process of enhancing the level of innovation and exploitation of technology relatively to our global competitors. As a result we expect to regain shares of the growing global market by improving our seafood quality, increase efficiency and reduce costs. This report is one of several from the project describing best protocol for handling, and storage in the edible crab fishery.

Acknowledgement

A big thank you to all!

Photos:
Mads Dorenfeldt Jenssen
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Protocol on Best Practice
Handling & storage of crustacean commodity at landing/recovery station
- edible crab

Table of content

1. Introduction

There is a significant export of live edible crab (*Cancer pagurus*) from Ireland and the UK to the European market, of which the majority goes to Spain and France, but also to Portugal, Italy and Germany. In addition there is also a domestic trade with live crab in all these countries. Crabs are also traded in Norway. Export of edible crab from Norway is mainly in frozen or processed form. This project aims to increase the survival and quality of live edible crab, from catchment to consumer. This will be by developing best practice protocols for handling on board fishing vessels, for transport through the value chain on land, and through technological innovations. The CrustaSea transport system described in the present report offers a technological solution for transport of live crabs from landing until deliverance at the final distributors serving end users or processing plants. A typical value chain for trade with the edible crab is illustrated below in Figure 1.

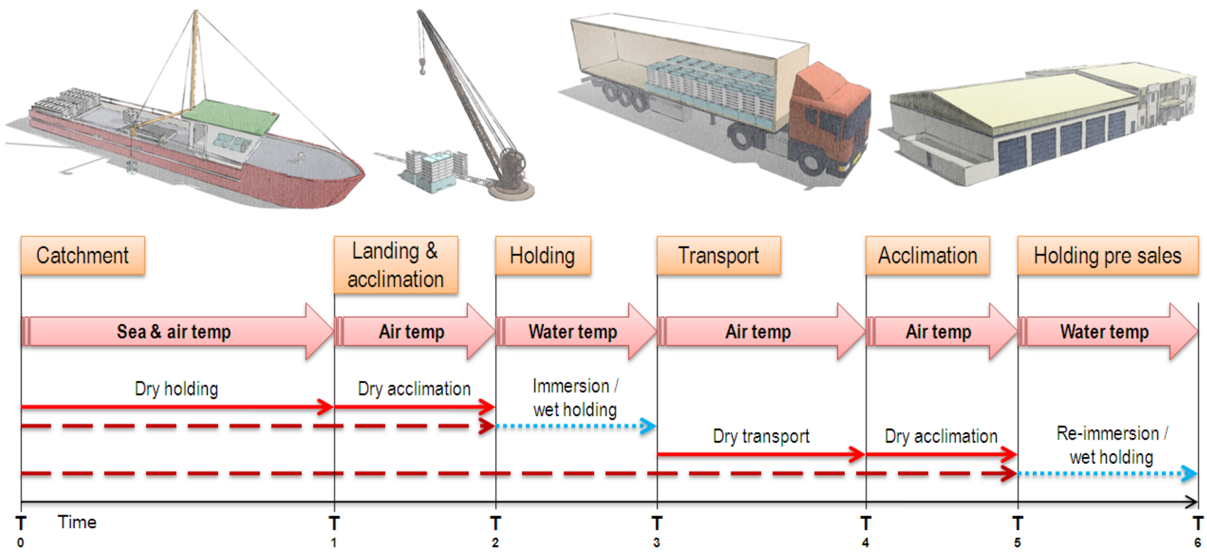


Figure 1 The value chain for live crab with key activities and processes through the chain using the CrustaSeaSystem. The T's in the timeline of the figure represents critical stages in the value chain when the product is handled and when special care needs to be taken in order to maintain quality and survival of the product.

2. Existing systems for Holding and transportation

2.1 Holding systems

There are several different methods and systems employed for storing live crabs, either at sea, submerged on land, or dry on land.

At Sea

When stored at sea the crabs are transferred from the fishing vessels to keep nets, cages, crates or boxes kept submerged in the sea until they are collected for transport. These systems are usually located in near proximity to harbours. This is a low cost way of holding live product, allows little control with water quality parameters. Such systems are also vulnerable to variations in temperature, salinity, and O_2 levels. In addition they offer no protection from possible pollutants.

Submerged On land

When storing crabs submerged on land the three most commonly employed systems are, flow through, recirculation and holding tanks supplied with pressurised air.

Holding tanks

This is the simplest and cheapest of the three systems. The crabs are transferred to sea water tanks, at a crab:water ratio of 50:50. Pressurised air is supplied to the bottom of the tanks. The air is used to remove CO_2 and to supply the animals with O_2. Since there is no supply of water to these tanks there is a danger that un-ionized ammonia excreted from the animals will reach lethal levels. Concentration above 1.4 mg/L of unionized ammonia is regarded as lethal to crabs, and will lead to mortalities.

Flow through system

These systems are the most common for storing live crab. The crabs are transferred to tanks supplied with a continuous flow of sea water. In such systems the animals are supplied with oxygen rich water, and metabolic waste products such as ammonia are continuously removed from the tanks. Given satisfactory water sources, these systems provide nice holding conditions with regards to essential water quality parameters. Unfavourable water temperatures will be the biggest risk with this system. However this can be counteracted by using chillers/heaters.

Recirculation systems

Similar to flow through systems, recirculation systems provide the crabs with a continuous flow of water. However, the effluent water is cleaned of accumulated wastes, such as CO_2, suspended solids and unionized ammonia through a process involving mechanical filters for removing solids, and bio filters for removing unionized ammonia. The CO_2 is removed by blowers, stripping the gas from the water. These systems are often used when sea water of sufficient quality is a restricted resource, or when there is a high demand for temperature control. Recirculation systems have similar operation costs compared to flow through systems, but they are more complex to run and maintain properly. Also these systems need a minimum water temperature of approximately 9˚C in order to keep the bio filter healthy. This is not necessarily a good thing, as one would like lower water temperatures to slow down the crabs' metabolism.

Dry cold storage

Crabs can also be stored in air as long as they are kept under moist conditions and at convenient temperatures. This is best done by using plastic boxes kept in a cooling facility. It is of vital importance that the crabs are sheltered from moving air/draft when stored in this way. Else, there is a risk of dehydration.

2.2 Transportation systems

Vivere Transport

When transporting live crabs over long distances (+24 hr duration), i.e. UK to European markets, vivier trucks is most commonly used. In vivier trucks the crabs are typically stored in 1000 l. tanks, filled 50:50 with crabs and water. To strip off accumulated CO_2 from the water, and to supply the animals with O_2 pressurised air is bubbled through the water from the bottom of the tanks. The main risk in these systems is accumulation of unionized ammonia. Unionized ammonia is a product of the animals' metabolism, and levels above 3-4000 µmole per litre is not uncommon to find in viviere trucks at the end of transport, such values are harmful and can be lethal to crabs (*Uglow and Hosie*. *1995*). Since the vivier tanks offer no cleaning of the holding water during transport, ammonia will accumulate and the concentration can reach high and harmful/lethal levels over time. The crabs metabolism, and thus the excretion of un-ionised ammonia, is temperature dependent. Thus, a lowering of the water temperature in the tanks will reduce the excretion of un-ionized ammonia. Vivier trucks only have the opportunity to chill the air inside the cargo compartment and not the tank water itself. This means that for all practical purposes the refrigeration systems of vivier trucks are only capable of keeping the water temperatures stable at the initial level. This is due to the large water volumes and high heat capacity of the water compared to that of air. Thus, vivier transport is highly dependent on the availability of sea water of low temperature for filling the tanks.

Crabs are to a large extent aggressive by nature. At high densities such as in a vivier tank the crabs will attack each other, clipping off claws and legs if given the chance. To prevent this, vivier transport of crabs is also **only** possible when the animals are "nicked". Nicking implies a physical cutting of certain ligaments in the claws. This is done manually and apart from being a time and resource consuming procedure, it is questionable if this is a violation of animal welfare acts. In many countries, Norway included, decapod crustaceans (crabs, lobsters etc.) are included in general animal welfare acts. In addition, the increasing consumer focus on animal welfare is likely to lead to negative public reactions at the habit of nicking crabs.

Dry live transport

Dry live transport of crabs is commonly used in Norway for transports limited to 24 hrs. There is no nicking of crabs in Norway. Aggressive behaviour is a minor problem since the animals are packed tightly in the transport boxes restricting their possibilities for movement and fighting. In addition, crabs stored under dry conditions adapt by retracting their limbs to reduce their surface and thereby potential loss of water due to evaporation. The main risks with dry transport are dehydration and accumulation of un-ionized ammonia in the animals. Therefore it is of vital importance that the crabs are stored at low and stable temperatures, and with restricted possibilities for air to circulate between the crab boxes. Low temperatures reduce the animals' metabolic rate, while a minimisation of draft prevents dehydration. The trucks used for dry transport are refrigerated, and temperatures are typically held around 4-6˚C.

Regarding animal welfare, crabs tolerate very well to be outside water for shorter periods. In fact, many species living in the tidal zone are adapted to dry conditions twice a day. Although this does not apply for *Cancer pagurus*, the potential stress linked to dry transport is regarded as insignificant compared to nicking.

An additional benefit of dry transport of crabs is the reduced risk for unwanted dissemination of alien species between geographically distinct regions. Transporting water from one region to another and between countries is also something that should be avoided, as such water can contain bacteria, viruses, and species alien to the area to which they are transported. Hence dry transport will dramatically reduce the risk of this happening.

3. The CrustaSea Holding and Transportation system

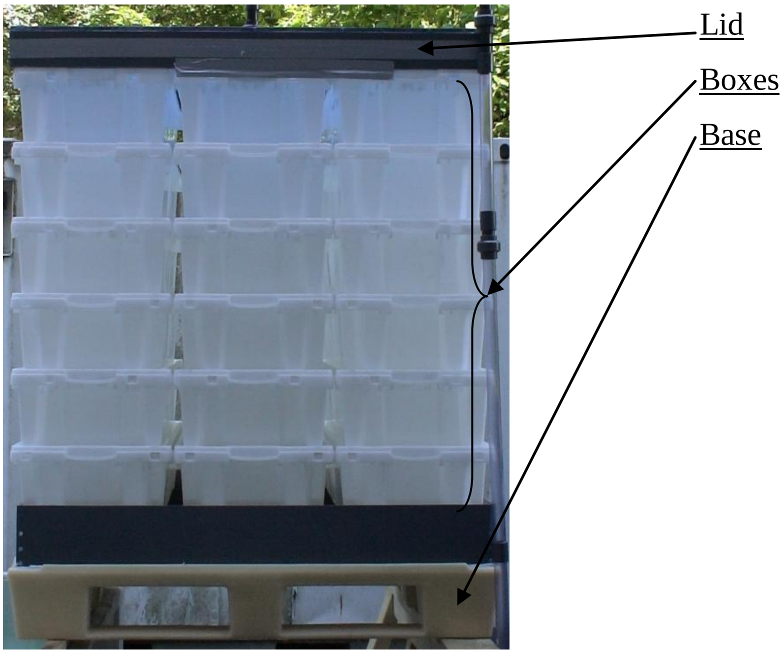
The CrustaSea system for holding and transportation of live crabs can be used in the entire commodity chain, from catchment to point of sale. The advantages of the system are several.

- The handling stress on the animals is reduced to a minimum. Following catchment, the crabs are stored in the transport boxes where they are kept unhandled during landing, transport and storage. There is no additional handling until final sales. Handling stress has been reported as one of the major causes and contributors to crab mortality when trading in live crab (*R H Mac Mullen et al 1996)*.
- The CrustaSea system offers possibilities for both wet and dry transport/storage without any repacking of the animals. This versatility makes it possible to exploit the benefits of both principles when appropriate.
- For return freight it is possible to stack the empty CrustaSea transport boxes inside each other instead of on top of each other, as they are stacked when under use. They will then occupy only one third of the initial volume. This makes the return transport more energy efficient and allows room for additional goods on the return freight.

3.1 System specifications

3.1.1 Each holding and transport unit consists of 3 main parts (picture 1):

1. 1 Water distribution lid.
2. 21 crab holding boxes in three 3 stacks, 7 boxes high.
3. 1 base fitting the Europallet standard



Picture 1 The transport and holding unit.

3.1.2 The main design criteria:

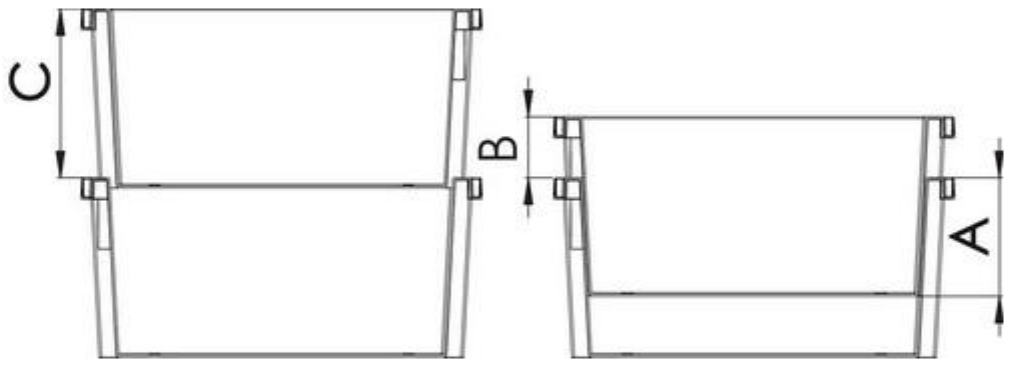
- Low cost.
- Volume effective for transport.
- Supply the animals with a sufficient water flow.
- Make nicking the crab redundant.
- No transportation of water.

The boxes:

The crustasea boxes are modified versions of regular boxes used for fish transport and storage. Each box has been equipped with 8 holes, 10mm in diameter (Fig. 6). Three slits have also been made near the top of one end of the boxes (Fig. 7). Each box measure L=800 x W=200 x H=400 mm., and have a net volume of 49 l. and a weight of 2,0 kg. The boxes are made from PE-HD plastic, an approved food grade material (picture 4.). The complete holding and transport unit consists of 21 boxes.

Picture 2. Unmodified Rebox from Norplasta: L = 800, W = 200, H = 400 mm.

The upper rim of the 2 short sides of each box has a unique design. During crab transport all boxes are stacked in the same direction. Thus, each box rests on top of the box beneath. During return freight every second box in the stack can be turned 180 ° relative to the others. Then each box will fit inside the box beneath (picture 5.) they are stacked. Stacked like this the complete unit (with lid and base) will occupy only 1/2 of initial volume. The extra volume made available in the cargo compartment of the transport trucks can be used for additional cargo on return freight, hence reducing the carbon footprint in relation to transport of brown crab.



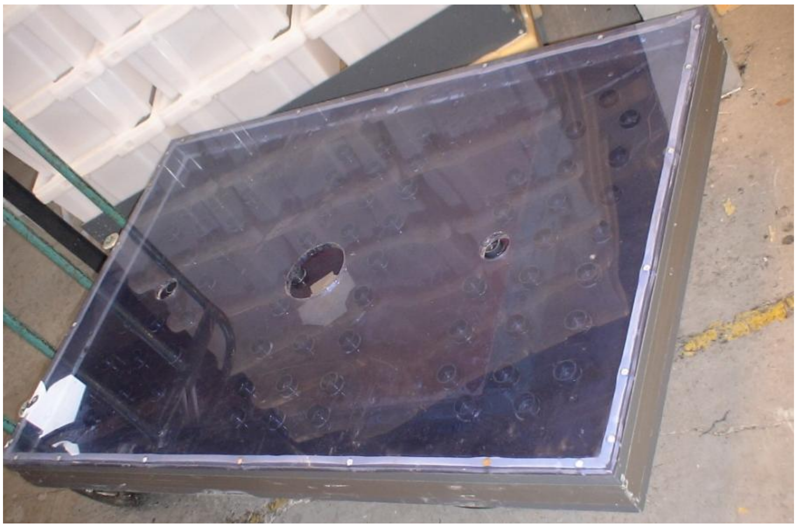
Picture 3. Box height, with and without product. 75% of total box height, A, is contained in the box below when stacked without product.

The water distribution lid

The lid is a rectangular box serving both as a water reservoir for even distribution of water to the boxes during wet transport/storage, and as regular lid during dry transport/storage. The lid fits exactly the top area of 3 stacks of transport boxes placed next to each other (picture 2.). The lids outer dimensions are L=120,5 x W=80 x H=10 cm, and its inner dimensions are L=116 x W=75,5 x H=4,3cm. The top plate of the lid is equipped with a circular 11.5 cm diameter hole at the centre, for connection with a water supply unit (fig. 3). The hole will match most water inlet arrangements at landing/holding stations. The bottom plate is perforated with 75 two cm. diameter holes (25 for each stack of boxes). A 3 cm long tube section has been glued to each hole on the inner side of the lid, elevating the 75 water outlets. This creates a 3 cm water level inside the lid ensuring an even distribution of water to the 3 stacks of boxes below.

Picture 4. Illustration of lid placed on transport and holding unit.

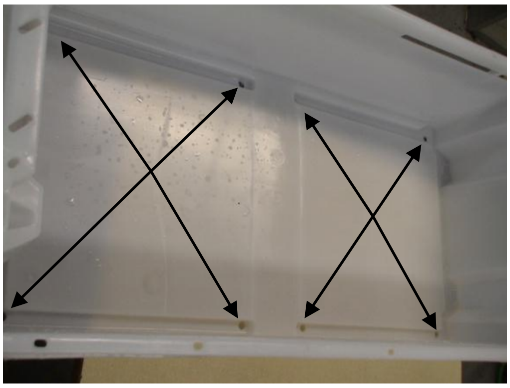
The frame of the lid prototype was made from PVC, and the top and bottom plates are made of from clear Acryl. The main reason for using transparent acryl was to be able to view how the water was distributed inside the lid. However, since acryl is a relatively heavy material it's recommended to use a more lightweight plastic material, such as PE-HD, for serial production.



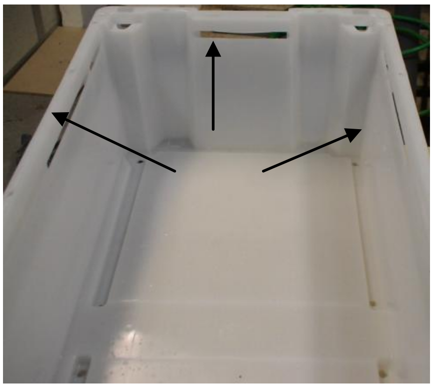
Picture 5. Showing water inlet, and the water distribution arrangement.

Wet transport

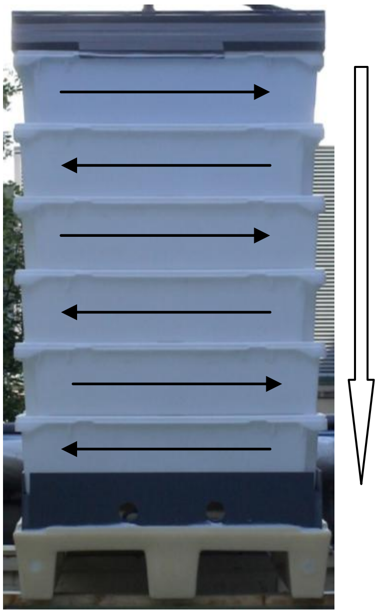
The custom made holes and slits in the boxes have been made for circulation of water during wet transport of crabs. Together the eight holes allow a flow through of 32 l min^{-1}. The slits allow additionally 50 l min^{-1} of water to be drained from each box, Thus, in order to fill the boxes with water, and to keep the crabs fully submerged, each stack of boxes needs a minimum water supply of 32 l min^{-1}. The slits work as overflows and come in use when the water supply exceeds 32 l min^{-1}, thus accounting for flexibility. Each unit can be used with water supply ranging from 96-246 l min^{-1} (32-82 l min^{-1} for each of the three stacks). For long time storage or transport it is recommended that the unit is used with a water supply in the upper part of this range. The reason for this is that the slits at the top then will create an optimal flow of water through the unit. When in use there is only one direction they can be stacked in order to rest on top of each other. When stacked correctly, the slits of one box will be located at the opposite end of the slits in the box above and beneath. The water will then be forced to run unidirectionally through the complete stack (Fig. 8). Approximately 50% of the boxes' volumes can be filled with live crabs. This corresponds to approximately 25kg of product per box, or 525 kg product per unit.



Picture 6 Showing holes for out flow.



Picture 7.Showing slits for outflow.



Picture 8 Arrows illustrating direction of water flow through the unit.

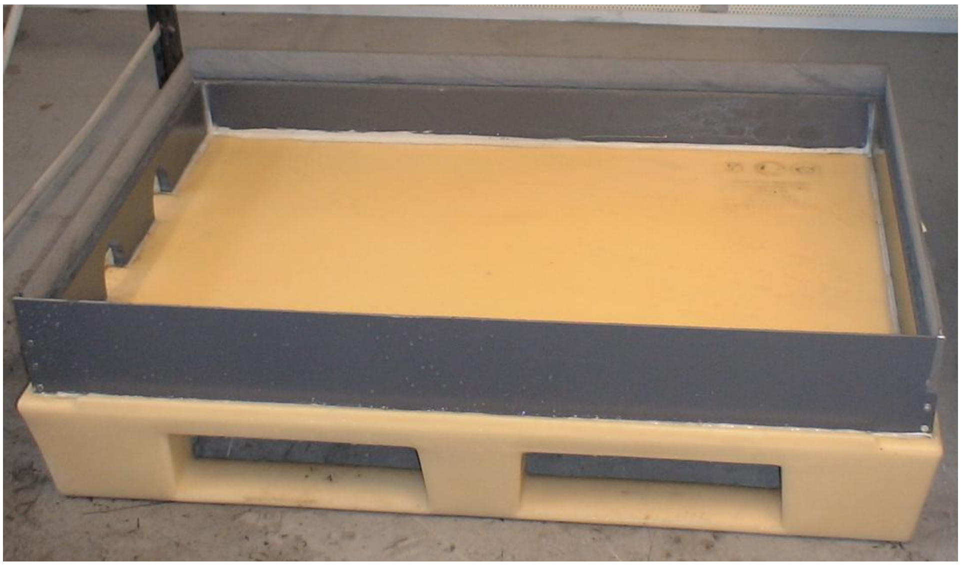
Dry transport

During dry transport the holes in the bottom of each box will drain water out of the boxes so the crabs will not be partially submerged in water excreted from the crabs. The slits at the top of the boxes will have no function during transport and/or storage.

As previously described it is of vital importancethatair is not allowed to circulate Through the unit during transport as this may take the moisture out of the unit and lead to dehydration of the crabs. The way the boxes are stacked allows little space for air to circulate and the moist air inside the has unit will not be replaced by potentially dryer air from outside.

The base

The base of the unit (Picture 9) is constructed as a plastic europallet (Promens, Type A108) fitted with a top frame of PVC. The dimensions of the pallet is 120 cm length x 80 cm width x 18 cm heigth. The weigth is 15 kg. The outer dimensions the frame is 117.5 cm x 77,5 cm x 15.5 cm. The inner dimensions are 117.0 cm x 77.0 cm x 9.5 cm. , The base is made from EU/FDA-approved foodgrade materials.



Picture 9. The base of the unit.

A double wall design of the frame (Picture 10.) elevates the bottom boxes off the pallet top ensuring no restriction of the water flow, and preventing accumulation of waste water during transport. The thinner top part of the frame (fig 10) adds stability to the unit and support to the boxes. One of the short sides is equipped with outlet holes (Fig. 11) that can be fitted to suit most outlet systems.

Picture 10. Showing the top of the pallet frame.

Picture 11. Transport and holding unit without product.

<u>The complete unit</u>

The total size of the unit without product is L=120 x W=80 x H=84cm, with a total weight of approximately 80kg (picture 11). ., comparatively the total height of the rig when holding product is 174cm, as seen in picture 12.

Picture 12. Transport and holding unit with product.

3.2 Cost of system

Some of the components of the transport and holding unit are off the shelf products with added modifications.

Without modifications the boxes cost 11.35€ when bought in small volumes, additional cost related to modifications (holes & slits) there will be an extra cost estimated at 0.6€ per box, resulting in a total box cost per transport and holding unit of approximately 250.95€. The box producer Norplasta, have confirmed that the boxes can be moulded with holes and slits.

When buying small volumes the pallet from Promens costs 118.3€ per pcs, the materials for the frame and work cost is estimated at 13.15€, giving a total cost per pallet of 131.45€. As with the boxes also the modified part of the pallet can be included in the mould for the pallet.

The total cost of the water distribution lid will be approximately 35.85€ including work and materials. This is rather high but that is because the prototype lid is made from expensive materials, such as Acryl, which would not be the case with a commercial product, and the price would be less.

The complete CrustaSea transport and holding unit will have a maximum cost of 418.25€ per unit (Table 1.). These prices are based on small volume purchases of materials and parts.

Table 1. Component and total cost of the transport and holding unit.

Component	Cost(€)
Water distribution lid	35.85
Modified boxes	250.95
Modified Euro pallet	131.45
Total	418.25

3.3 Water quality parameters

The most important water quality parameters that should be controlled during transport and holding of Brown Crab (Cancer Pagurus) are temperature, oxygen, salinity, CO_2, pH, ammonia, nitrites and nitrates.

3.3.1 Temperature

The temperature has a significant impact on biological, chemical and physical processes in water. All aquatic animals are highly influenced by the water temperature, as it has direct impact on welfare, activity levels, behavioural patterns, feed uptake and metabolism. As poikilothermic animals, crustaceans have body temperatures equal to the ambient temperature. The water temperature will therefore determine the metabolic rate and not opposite as seen in homeothermic animals. The metabolic rate of aquatic animals decreases with decreasing temperature. This represents an advantage for storage and transport of live crabs. At low temperatures, crabs' oxygen consumption decreases. This in turn increases the animals' ability to tolerate stress (Liltved & Maroni 1988). Also, the production of waste products from metabolism (e.g. CO_2, ammonia, nitrites and nitrates) decreases with decreasing body temperature/metabolism.. In the wild the optimal temperature range for the Brown Crab is 8-20°C. During storage without feeding, the optimal water temperature, measured as maximum survival, is in the range 2-5°C. The water temperature also affects the solubility of a given gas in water. The higher the water temperature, the less gas can be dissolved in the water.

3.3.2 Salinity

Oceanic sea water has a stable salinity of about 35 ‰. In coastal areas, especially in fjords the salinity will often be lower, and may also vary considerably, due to fresh water influence. Rivers, rain fall and melting snow may cause rapid changes in salinity. Crabs should be held in water with salinity no less than 30 ‰ (Woll 2006).

The solubility of gases decreases with increasing salinity. The reduction in solubility of gases with increased salinity can be explained by the fact that when salinity increases, more water molecules are involved in dissolving the salts. Therefore less water molecules are available to dissolve gases and gas solubility decrease.

3.3.3 Gases in water

There is a constant exchange of gases between water and air. Under normal conditions the gases present in the air are therefore also found in water, at the same partial pressures as in air. However, the water solubility of the specific gases varies and therefore the proportion of the gases differs in air and water. For instance, relative ratio of O_2:N_2 is 1:2 in fully (100 %) saturated water instead of 1:4 in pure air (Wheaton 1977).

Table 2. Gases in dry atmospheric air at sea level

Gas	Weight (%)	Volume (%)
Nitrogen, N_2	75.54	78.084
Oxygen, O_2	23.10	20.946
Argon, Ar	1.29	0.934
Carbon dioxide, CO_2	0.05	0.033
Other gases	0.02	0.003

Oxygen

There is a passive exchange of gases between air and water. The gas exchange is usually a slow process that is dependent on the size of the contact area between air and water (Wheaton 1977; Tvenning 1993; Gebauer et al. 2005). The temperature and the pressure influence the diffusion rate, which is the main driving force for oxygen transfer (Wheaton, 1977).

Table 3. Solubility of oxygen in fully saturated (100 %) water at normal atmospheric pressure

Temp	Solubility in seawater at 35‰ salinity (mg/l)
0	75.54
5	23.10
10	1.29
15	0.05
20	0.02

In crustacean gills oxygen diffuses between the water and the blood. The diffusion rate is therefore highly dependent upon the partial oxygen pressure in the water. The available oxygen in the transport and holding unit should therefore be measured as the saturation value (%) of oxygen (which is not dependent of temperature, salinity and atmospheric pressure) rather than in mg O_2 per litre (Liltved & Maroni 1988; Tvenning 1993; Seafish 2002; Gebauer et al. 2005). The saturation value should not be lower than 80 % for crabs during storage. If there is too little oxygen in the water that is available for the crabs, they will shift from aerobic to anaerobic metabolism. The crab will then start to accumulate waste products in its body that will essentially reach toxic levels depending on time, temperature and other welfare parameters (Woll 2006).

Carbon dioxide

As a metabolite, the rate at which CO_2 is produced is dependent on the metabolic activity of the animal. In poikilothermic animal the metabolism varies with temperature. Thus the rate of CO2 production increase with increasing temperatureThe CO_2 content can reach toxic levels if it is not removed at a sufficient rate. If carbon dioxide accumulates in the water, the gas will diffuse over the gills and accumulate in the blood. CO2 reacts with water according to the reation: $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO3-$. Thus with increasing CO2 levels the concentration of H+ ions will increase. This is recognined as a low pH value. Low pH value of water may therefore indicate too high levels of metabolic CO2.

Nitrogen

Air supersaturation, especially nitrogen supersaturation, is brought about when water warms up or is heated. It can also occur at the pressurization of the water in the water piping system, and when a water collection system draws air somewhere. Saturation of nitrogen should not be higher than 100 % and must be kept below 103 - 105 % to avoid acute physiological responses, such as the gas bladder disease. This disease is comparable to the decompression sickness, or “the bends”, which can be inflicted on human divers after a rapid surfacing (Liltved & Maroni 1988; Seafish 2002). Carbon dioxide and gaseous nitrogen (N_2) are traditionally removed by aerators (Losordo et al. 1998; Masser et al. 1999; Gebauer et al. 2005).

Argon (Ar) is classified as a inert gas, with very low to no reactivity with other elements. It makes up approximately 1% of the earth’s atmosphere. Argon is always present in a constant ratio to nitrogen, and hence, for the purpose of supersaturation of gases, nitrogen and argon are treated as one inert gas. The two gases are often termed “Nitrogen” in the fish farming industry.

Ammonia and ammonium

Ammonia (NH_3) is a product of the crabs' metabolism, and is mainly secreted by the animals through the gills when the crab is immersed (Woll 2006).. NH_3 are highly soluble in water where it forms the equilibrium: $NH_3 + H^+ \leftrightarrow NH_4^+$ Tvenning 1993) When a crab is exposed to air, for instance under dry transport/storage ammonia will accumulate in the crab.When the crab is once again re-immersed in the holding unit, it will excrete most of the accumulated ammonia immediately (5-10 min), in addition to its stomach content and excrements (Woll 2006). High levels of ammonia in the water can be toxic to the crabs. Thus it is essential that the water flow is high enough to prevent the ammonia in the water to reach toxic levels.

The chemical balance between ammonia NH_3 and ammonium $NH_4^+$is regulated by the pH-value and the water temperature. Although, ammonia (NH_3) is much more toxic than ammonium (NH_4^+) for crustaceans, the ammonium (NH_4^+) can cause welfare problems for the animals at low pH values when there will be an excess of NH_4^+ (toxic at high concentrations). On the contrary, an increased pH-level will shift the balance towards the highly poisonous ammonia (NH_3). Thus it is important to be able control levels of both the highly poisonous ammonia and the less poisonous ammonium (NH_4^+) concentrations (Terjesen & Rosseland 2009).

Hydrogen sulphide

Hydrogen sulphide (H_2S) is a gas produced throughanaerobic decomposition of organic material. H_2S is highly toxic to aquatic animals, and the toxicity increases with higher temperatures and lower pH values (less than 8), when the largest percentage of hydrogen sulphide is in the toxic unionised form. In stagnant water such as in pipes and hoses, H2S can be formed after only a short period. To prevent water containing H_2S to enter the transport and holding unit, all water supply pipes should be flushed for a short period before they are connectedto the transport and holding unit.

3.3.4 Water mixing and flow in the transport and holding unit

During holding of live crab, water flow ensures a stable supply of new water, enabling a homogenous supply of O_2 in the holding units. The transfer of oxygen within water mass is almost entirely dependent on water movement, since the diffusion of oxygen within water is extremely slow. For example, it has been calculated that to raise the oxygen content at a depth of 10 meter from 0 mg/l to 0.4 mg/l by passive diffusion alone would take about 600 years (Wheaton, 1977). This emphasises the need to ensure good mixing within transportation and storage unit to avoid the development of stagnant areas with continuous decrease in O_2 levels and increase in CO_2, Ammonia, nitrites and nitrates.

4 Guidelines for live storage and transportation using the CrustaSea system

In the present project, live storage is defined as short time holding of live aquatic animals for sales or value adding purposes, without feeding. It is vital when trading live animals that the entire value chain is treated as one entity, from catchment to end user. No matter where in the chain the animals are, sub optimal treatment will have a negative affect on the overall survival and the quality of the end product. The crab industry should develop a complete transport and holding plan from catchment to end user, with special focus on temperature. The transport plan used by the aquaculture industry when transporting live fish from hatcheries to on-growing units could be used as a model. The temperature should be logged and communicated through the value chain from the fishermen, holding stations, transport and end stations to avoid abrupt changes in temperature. Handling of the crabs, both duration and the number of events, should be kept at an absolute minimum, as all handling will induce stress and thereby increase the animals' metabolism. The accumulative effect of such handlings will lead to increased mortality.

Table 4. **Value Chain for Live Brown Crab (*Cancer Pagurus*).** Comparison of procedures and handling of Live Crab through three alternative value chains, from catchment to end user.

Vivier boats	In shore boats	CrustaSea system
Pot	Pot	Pot
Nicking	Nicking	No nicking needed
Transfer to hold	Transfer to box	Transfer to box
Transfer to landing station or direct to truck	Transfer to landing station or direct to truck	Boxes transferred to CrustaSea holding & transport system.
Transfer to tanks at reception facility		No individual handling until sale

4.1 Landing and pre transport

After catchment crabs are stored on board the fishing vessels in two ways, either in water tanks (mainly larger vivier boats) or under dry/moist conditions in boxes (mainly smaller fishing vessels). From the boats the crabs are either transferred directly to vivier trucks or to holding stations on land prior to further transport. From vivier boats the crabs are transferred from the water tanks via dry boxes to vivier trucks or storage facilities where they once again are transferred to water With the CrustaSea system, the crabs can be distributed to the transport and holding boxes immediately after catchment and there will be no subsequent need for redistribution and or individual handling. Once in the boxes, the crabs will be moved together with the boxes and/or transport unit all the way to final distributor or outlet. Through the value chain the unit can be kept dry or supplied with water at any time as it suits each link in the chain. It should however, be stressed that transport/holding of longer duration requires that the Crustasea unit is supplied with water, allowing the re-immersed crabs to rid themselves of accumulated waste products such as lactate and ammonia. While ammonia is flushed from the crabs within minutes (5-10mins after re-immersion), it can take up to 24hrs for the crabs to rid themselves of accumulated lactate. The time needed depends on temperature, the time the animals have spent out of water and how stressful the catching process has been for the animals.

Temperature, from catchment to landing & storage.

For minimum mortality and optimal quality of the live product it is of vital importance that the temperature is kept as stable as possible. Any changes in temperature may cause stress related mortalities and sudden shifts in temperature of 6˚C or more should never occur. In order to achieve this there should be an overall transport plan that is communicated through the value chain, with particular emphasis on:

- Sea Temperature
- Time from catchment to landing
- Water temperature at landing station
- Air temperature at landing station
- Time of departure for further transport

Upon catchment the crabs will have a temperature close or equal to that of the sea temperature where they were caught. If stored dry/moist onboard their internal temperature will gradually be altered towards the air temperature at a rate of about 2˚C/hr. This can be used a rough guide to predict the future temperature of the crabs, for instance at the time they are landed. Temperature acclimation of crabs is better done when they are kept in dry conditions rather than submerged. Compared to the 2˚C/hr change under dry conditions, the internal temperature of submerged crabs will change to the ambient temperature almost instantly.

Example of temperature change from catchment to landing.

Crabs were caught at 09:00 hrs at a sea temperature of 8˚C, and an air temperature of 16˚C. Time from catchment to landing was 3 hours and the water temperature at the landing station was 12˚C.

The internal temperature of the crabs on arrival at the landing station would then be approximately 14˚C (8˚C + 3hr X 2˚C/hr).

The 2 °C difference in temperature between the internal temperature of the crab and the water source at the landing station would not represent any problems for the crabs and they could be supplied with water without any adaptation. Differences less or equal to 4˚C require in general no intermediate acclimation or adjustment of the water temperature.

Following landing the boxes filled with crabs should be stacked on the unit base as illustrated in picture 13. One full unit consists of 21 pcs 49L boxes, each with 20-25 kilo of crab.

Picture 13 CrustaSea holding & transport system

When stacking the boxes care should be taken to avoid legs/claws to be caught between boxes. When the CrustaSea unit is full, the lid should be fitted on top and and the complete unit transferred to the holding facilities and supplied with water. For the first 15 minutes it is important that the water flow is in the upper part of the recommended flow range (96-246 l min-1) to ensure that all crabs in the unit are submerged as soon as possible and to ensure rapid removal of metabolic waste products. After the first 15 minutes the flow can be reduced.

When used wet, the oxygen levels in water of the bottom boxes should be monitored. Ideally the oxygen level in these boxes should not be below 80% saturation, but if water is a limited resource and extra oxygenation is impossible a 65% O2 saturation in the bottommost boxes is acceptable for 24 hour storage. This can however increase the risk of mortality. The oxygen levels in the system will stabilise after approximately one hour.

<u>Monitoring the system during storage.</u>

As previously described the oxygen saturation levels can be used as rough indication of the condition of the crabs in the holding system. This can be done by monitoring the O2 saturation both in the inlet water and in the bottommost boxes of the holding system.

1. If the oxygen level in the bottommost boxes keeps stable throughout the duration of the holding period the crabs are ok.
2. If there is a gradual to sharp increase in oxygen levels in the bottommost boxes while the oxygen level in the inlet water remains stable, it is likely that crabs are dying (less crabs to consume O2). The more crabs that die the higher the oxygen level in the bottommost boxes will become.
3. If the oxygen level in the bottommost boxes decreases while the level in the inlet water remains stable it means that the crabs have either increased their metabolism or that the water flow to the system has decreased. Preventive action in both cases is to increase the water flow and thereby increase the level of oxygen in the system. If there is an oxygenation system available and the flow is stable, simply increase the oxygenation of the water for the unit.

Storage, preparing for dry transport

When preparing for transport the water supply to the CrustaSea system should be turned off about one hour prior to transport. This will both let the system drain completely and allow the crabs to calm down (shutting off water will initially induce increased activity).

During transfer the CrustaSea units should be protected from direct sunlight until they are loaded onto the lorry. The time it takes to load each unit can be reduced to a minimum by using a forklift, thus minimizing the time each unit is exposed to potential direct sunlight and draft during the loading process.

If the cargo compartment of the transport truck is equipped with air conditioning/chilling system care should be taken to protect the crabs from circulation chilled air as this may dehydrate the animals and thereby increase the risk of mortalities.

4.2 Transportation

The crabs should be transported between 2-5˚C. When kept dry (moist) at this temperature the crabs will remain in good condition for approximately 60 hours, provided that previous handlings have been gentle. Outside of water the crabs' gills collapse and the excretion of waste products over their gills is paused. Instead the metabolites are accumulated in the body at a rate depending on the ambient temperature. This is why it is important to keep the animals chilled (2-5˚C) so that the metabolic rate is reduced to a level where accumulation of waste products is at no risk of reaching dangerous levels. There are several advantages with dry transport compared to the traditional viviere-transport. With viviere-transport one transports 50% water and 50% crab, in addition there has to be a central corridor in the hold of the lorry to allow for movement, as shown in picture 14. The CrustaSea system will utilise all of the floor space and there will be no additional weight due to transportation of water. This is also an environmental advantage, as when transporting water from one geographical area to another there is always a risk of unintended spreading of alien species, with dry transport this risk is significantly reduced.

Picture 14. Interior of a vivier lorry

Transport, preparation for transfer to end station

As mentioned previously, a detailed transport procedure with special emphasis on the temperature should be developed for all value chains. It is then of vital importance that this procedure is followed. Before landing and transport, the transporter should know in detail the conditions the crabs will be subjected to at the end station, so an acclimation to this regime can start during the last stages of the transport. If crabs from one landing are to be delivered at multiple locations, the acclimation should aim to fit an estimated average of the conditions at the landing stations. Final acclimation is then done at the end station. This should be done under dry conditions and out of draft. . Only when the temperature in the CrustaSea unit is within a 4˚C deviation from that of the water source the water supply may be turned on. This procedure is exactly the same as when transferring crabs from boat to landing station.

Example of temperature acclimation from transport to end station.

Crabs transported dry at 5˚C.
=> The internal temperature of the crabs when arriving at the end station will be 5˚C.

The air temperature at the end station is 16˚C.
The water temperature at the end station is 12˚C.
=> Acceptable internal temperature for the crabs is 8˚C (4˚C difference from water source).
=> Time needed for acclimation will then be approximately 2 hours (5˚C + 2hours X 2˚C/hr = 9˚C).

This 3˚C difference in temperature between the internal temperature of the crab and the water source at the landing station is thus within the safe temperature range for re-submersion of the crabs using the water source at the end station. In order to save time the acclimation should preferably be done in the transport lorry prior to arrival. Since the temperature in this case should be elevated, this can simply be done by turning off the cooling system in the lorry at adequate time before arriving. This requires that the lorry has a control system for monitoring the temperature.

4.3 Reception and holding at end station

Upon arrival at the end station the CrustaSea units should immediately be transferred to the holding areas and prepared for re-immersion. The water should however, **NOT** be turned on (as mentioned in 4.2) until the crabs have been properly acclimated to the water temperature at the end station. Even though it is important to re-submerge the crabs after a long period in dry/moist conditions it is even more important for survival to avoid sudden changes in temperature. It is also important that the crabs are protected from direct sunlight and draft. When the crabs have been acclimated to the water temperature the water should be switched on. The water flow should be as high as possible for the first 10 minutes to flush the ammonia that have accumulated in the crabs and is released as a response to re-immersion. At the end station a water supply with temperature control is of course most beneficial. First, the temperature can be adjusted to the crab's temperature at arrival, so no dry acclimation is needed. Second, the temperature can be optimised during the holding period. It should be reminded that optimal temperatures for crabs during holding differ from the optimal temperature required for growth in the wild. A stable temperature within 2-5˚C is preferred to ensure high O2 saturation in the water, and low metabolic rate in the crabs. Stable environmental conditions are also important to keep the crabs calm. Controlling these factors is the best contribution for keeping the crabs in prime condition through storage.

Assessing the survival

Catchment, handling and transport is stressful for live animals. Crabs are no exception. Therefore, mortality may occur. Checking for and removal of dead animals should ideally be done prior to transport. However this represents additional handling that could stress the crabs further and cause even higher mortality. As previously described in detail, measuring oxygen levels in the transport units is a rapid and gentle way of assessing survival after transport without handling the crabs directly. It is recommended that this procedure is followed. If there are indications of considerable mortality in any units they should be checked and dead animals removed. However, in any case the units should be left for at least 1 hour after connecting the water to allow the animals to recuperate after transport. As a general rule, 15-20% difference in oxygen saturation between the inlet and outlet water is an indication that the crabs are consuming oxygen and are healthy. Less than 5% difference in the oxygen saturation between the inlet water and the outlet water it indicating that too few live animals are consuming oxygen. These units should be inspected and any dead animals should be removed.

As part of the transport and holding procedure, the oxygen saturation for the inlet water and outlet water of each unit should be logged in addition to a temperature log of the inlet water temperature. When the temperature increases there will be less oxygen dissolved in the water, hence the flow to the holding units needs to be increased in order to maintain the same level of oxygen dissolved as prior to the temperature increase. Similarly the flow to the units can be decreased when the temperature drops, as the amount of oxygen that can be dissolved in the water will increase. It is very important to always monitor oxygen levels after adjusting the flows to the units, as it will take a little time to stabilise.

The time from catchment to sale should be minimised. Crabs will keep in good conditions for approximately 7 days if handled correctly. After seven days mortality has to be expected, as a result of starvation. The crabs should be sold or processed before this time.

References

Gebauer, R., Eggen, G., Hansen, E., Eikebrokk, B. (2005): Oppdrettsteknologi: Vannkvalitet og vannbehandling i lukkede oppdrettsanlegg. Tapir Akademisk Forlag, Trondheim, 576 pp. (in Norwegian)

Liltved, H., Maroni, K. (1988): Oppløst gass i ferskvann og sjøvann til fiskeoppdrett. Norsk Fiskeoppdrett, pp. 38-42. (in Norwegian)

Losordo, T.M., Masser, M.P., Rakocy, J. (1998): Recirculating Aquaculture Tank Production Systems – An Overview of Critical Considerations. SRAC Publication, 451, 6 pp.

MacMullen, R.H. et al. (1996). An Assessment of Damage and Mortality of the Brown Crab during Vivier Transport.

Masser, M.P., Rakocy, J., Losordo, T.M. (1999): Recirculating Aquaculture Tank Production Systems – Management of Recriculating System. SRAC Publication, 452, 12 pp.

Seafish (2002): Control of Supersaturation in the Hatchery. Aquaculture System Report. Seafish Aquaculture. Ardtoe, May 2002. 15 pp.

Terjesen, B.F., Rosseland, B.O. (2009): Produksjon og giftighet av ammoniakk hos fisk. Norsk Fiskeoppdrett, 2 (2009), pp. 52-55. (in Norwegian)

Tvenning, H. (1993): Akvateknikk 1: Vanntransport - Vannbehandling. Universitetsforlaget, Oslo, 151 pp. (in Norwegian)

Uglow and Hoise (1995). The live marketing of Irish brown cra: an investigation of the effects of current procedures on the quality of delivered product. A study by the University of Hull commissioned by An Bord Iascaigh Mhara. Unpublished.

Wheaton, F.W. (1977). Aquaculture Engineering. Wiley, New York.

A.K. Woll (2006). The Edible crab. Biology – Grading – Handling live crabs. Møreforsking. Ålesund, Norway, March 2006. 32 pp.