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Comparison of transport modes and packaging methods for fresh fish products – storage life study and life cycle assessment

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Report summary

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Ágrip á íslensku:	Mikill ávinningur er í bættri stjórn á virðiskeðju útflutnings á ferskum fiskhnökkum til dreifingar í verslanakeðjum í Bretlandi. Með bættum aðferðum við pökkun væri hægt að auka geymsluþol vöru, sem er grundvallaratriði í þessum viðskiptum. Með loftæmdum umbúðum væri hægt að flytja vöru í krapakeri með lágu hitastigi (niður í -1 °C) sem bæði myndi lækka flutningskostnað verulega og gæti jafnframt lengt geymsluþol vörunnar. Einnig gefur aðferðin möguleika á pökkun með neytendaupplýsingum sem gerir frekari pökkun erlendis óþarfa. Í flutningi með flugi væri hægt að pakka allri vöru í 12 kg frauðplastkassa í stað 3 kg, eins og algengast er í dag, og spara þannig verulegan flutningskostnað. Notast var við hitamælingar, skynmat, efna- og örverumælingar og lífsferilsgreiningu til að bera saman mismunandi pakkningalausnir fyrir sjó- og fluflutning. Ferskir ýsubitar í lofttæmdum umbúðum í keri með krapaís, sem geymt var við dæmigerðan hita í gámaflutningi, reyndist hafa 3–4 dögum lengra geymsluþol en hinir tilraunahóparnir, væntanlega aðallega vegna betri hitastýringar. Samræmi milli niðurstaðna skynmats og örverumælinga var almennt gott. Lægstu umhverfisáhrif allra hópa voru kerahópsins með sjófluttar, lofttæmdar umbúðir en þá útfærslu mætti enn frekar bæta með tilliti til blöndunar ískrapans og fiskhitastýringar og þar með geymsluþols.		
Lykilorð á íslensku:	*Ferskur fiskur, flutningsmáti, frauðplastkassi, ker, geymsluþol, skemmdarbakteríur, lífsferilsgreining*		

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Icelandic Food and Biotech R&D

Report summary

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Summary in English:	The aim of the project was to compare alternative packaging methods of fresh fish loins to the traditional packaging. Comparison was made between packages in terms of temperature control and product storage life by simulating air and sea transport from Iceland to UK in air climate chambers. The evaluation was made by the sensory panel and microbial- and chemical analysis by the Matís laboratory in Reykjavík. Furthermore, the environmental impact of the aforementioned transport modes and packaging methods was assessed by means of LCA (Life Cycle Assessment). About 70–75% of Iceland's exports of fresh fillets and loins are transported by air and the rest by container ships. Increased knowledge on the advantages and disadvantages of the packages used for this fresh fish export will facilitate the selection of packages and improve the quality and storage life of the products. By using vacuum-packaging it is possible to use 12 kg packages in air freight instead of the traditional 3–5 kg packages; but the market is increasingly demanding smaller individual packages. Sea transported larger packages use less space in shipping, lowering freight cost and environmental impact. Vacuum packed haddock loins immersed in slurry ice in a fish tub stored at sea transport temperature conditions proved to have a 3–4 day longer storage life than all the other experimental groups, probably mainly because of better temperature control. Good agreement was obtained between the sensory- and microbial evaluation. Finally, the sea transport-tub-group was found to be the most environmental friendly and could be improved with regard to product temperature control and thereby storage life.
English keywords:	*Fresh fish, transport mode, EPS box, tub, storage life, spoilage, bacteria, life cycle assessment*

CONTENTS

1 INTRODUCTION

Storage life of fresh whitefish products (processed from gutted, iced whitefish) is highly temperature dependent (Figure 1) and usually ranges between 10–13 days assuming storage at 0–1 °C (Lauzon et al., 2010a).

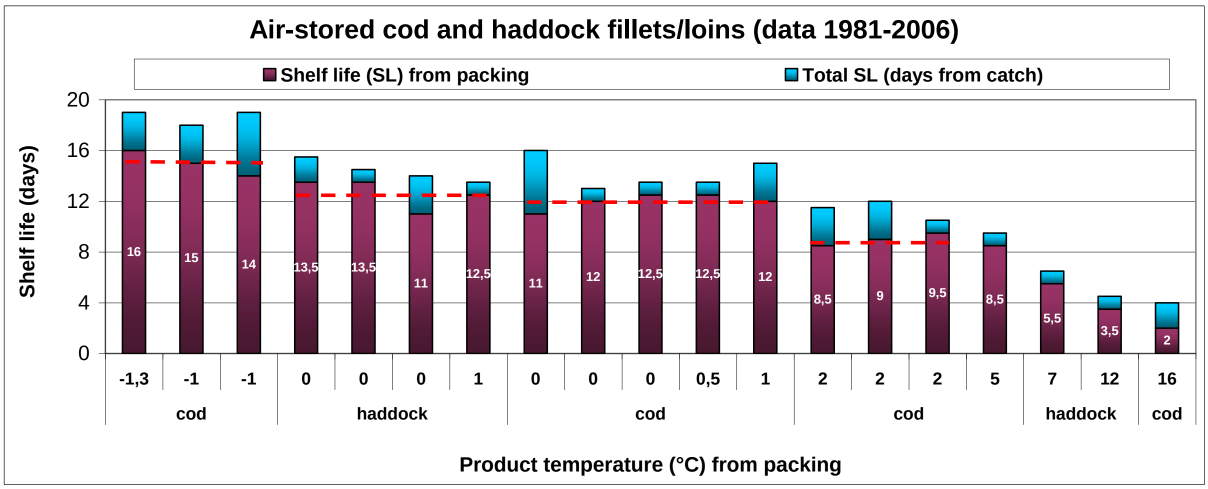

Figure 1. Effect of temperature on the storage life of cod and haddock products (Lauzon et al., 2010b).

Low and stable transport temperatures are required to maintain fish quality as delivery of high value products is of outmost importance. Temperature fluctuations during air transport can lead to a reduction in storage life of 1.5–3 days depending on the box position on the abused pallets compared to steady storage at –0.4 °C (Margeirsson et al., 2012c).

The objective of the current study was to compare the use of traditional EPS boxes with use of new 340 L (PE tub) from Promens (Dalvík, Iceland) in transporting fresh fish portions by air and container ship.

The trial was performed by Matís and Icelandic saga and supported by Atvest, an economic development agency for the Westfjords region of Iceland. Processing was performed by Matís staff at Icelandic saga processing facility in Suðureyri, Ísafjarðarbæ. Research and evaluation was executed by Matís, Vínlandsleið in Reykjavík.

The growing human population and our mutual problems concerning the environmental impacts of our production and consumption call for immediate and increased actions regarding the pressure on the earth's ecosystem. By using a tool like Life Cycle Assessment, a greater efficiency in production, transport and usage can be reached, which can drastically lower the outputs of harmful materials entering the atmosphere.

The life of every product starts with the design/product development, and from that point adoption of resources and raw materials, production, use and end of life activities. Life cycle assessment (LCA) is a methodology used to estimate and evaluate the environmental impacts of a product's life cycle. Life cycle assessment is a standardized methodology by the ISO standard 14040 series (ISO 14040:2006(E)).

2 METHODOLOGY

2.1 Experimental design

2.1.1 Raw material

The raw material used in the experiments was caught by two long-liners, Einar Halfdánsson and Sirry, North West of Deild, outside the Skálavík in North West of Iceland, 18th of August 2012. After bleeding in cold seawater the fish was put in slurry ice tubs in insulated fish holds of the vessels. The trip lasted from 6:00 in the morning until 19:00 in the evening. Fish-tubs were unloaded from fishing vessels in Bolungarvík and trucked to Suðureyri that evening, around 40 km distance, to the fish factory of Icelandic Saga. There the fish was gutted, headed and washed before being stored in slurry ice tubs in the chill room. After 3 days of storage the fish was filleted and trimmed on a flow-line system at Icelandic Saga. This day production was ongoing for fresh fish export to Immingham by container ship. Until packing to four different packaging types for the experiment, the whole process was identical for the Immingham export and the experiment.

The four experimental groups are shown in Table 1. Sampling on day 1 represents the day following the day of processing and packaging, which took place four days post-catch.

Table 1. Overview of the experimental groups and the corresponding sampling days post-packaging for sensory evaluation and microbial measurements. Legends: Sea: simulated sea transport conditions, Trad: traditional packaging method, Air: simulated air transport conditions, IP: individually packed

Group	Sampling days
Sea-Trad, 5 kg	7, 9
Sea-Tub, IP	1, 7, 9, 13
Air-Trad, 5 kg	7, 9
Air-IP, 12 kg	1, 7, 9

Below, the packaging methods applied to the four experimental groups are described in more details.

2.1.2 Sea-Trad, 5 kg (EPS boxes – 5 kg for container ships)

Traditional product was packed in 5 kg EPS boxes for container shipping. One ice pack (weight: 250 g, manufacturer: Promens Tempra, Hafnarfjörður, Iceland) was laid on the top of the product and the lid sealed by tape. The boxes were then treated like any other shipment of fresh fish, by storage in a frozen storage room for couple of hours. This same day, the same product was processed for export to Immingham, and the samples received the same kind of treatment.

Figure 2. Haddock loins in a plastic bag inside an EPS box. According to the industrial standard, the ice pack was put on top of the loin stack in each EPS box (not below the loins as shown in the figure).

2.1.3 Sea-Tub (PE tub from Promens)

The PE tub was filled with slurry ice, which was made by mixing around 200 L of fresh water and 2 kg of salt in addition to 50 kg of ice. Because of the salt the temperature of this brine decreased to around −1 °C. Following this, 200 kg of haddock loins

Figure 3. Haddock loins in a plastic bag.

were vacuum packed, 4 portions in each bag, and dumped in to the tub. The temperature of the product was around 4–5 °C when packed. The product temperature was decreased below 0 °C in around 2–3 h in the slurry ice tub. When the tub was filled up it was moved to the reception room, the water was partly drained from the tub and was then ready to be shipped to Reykjavík. The tub was kept under unchilled conditions for around 4 h longer than the other groups before the land transport to Reykjavík.

2.1.4 Air-IP, 12 kg (Individually packed in 12 kg EPS boxes for air freight)

The same product as for the PE tubs, vacuum packed, was packed in 12 kg EPS boxes, 12 to each of 5 boxes. Two ice packs were laid on top of the product and the lid sealed with tape. The boxes were then treated like any other shipment of fresh fish, by storage in a frozen storage room for a few hours.

2.1.5 Air-Trad, 5 kg (EPS boxes – 5 kg for air freight

A traditional product was packed in 5 kg EPS boxes for air cargo. One ice pack was laid on top of the product and the lid sealed with tape. The boxes were then treated like any other shipment of fresh fish, by storage in a frozen storage room for a few hours.

2.1.6 Conditions during processing

It was a warm day in Suðureyri (Vestfjords, NW-Iceland) at the day of processing, 19 °C and sunny. The temperature in the processing hall was around 20 °C with processing water temperature around 4 °C. This same day the factory was processing haddock portions for Britain, which were shipped to Immingham by Eimskip in a container ship. Samples for this project were processed and handled the same way as this production, except for the individual vacuum packaging.

2.2 Temperature measurements

IButton temperature loggers (DS1922L) from Maxim Integrated Products (see Figure 4) were used for all temperature monitoring in the trial. This logger has an accuracy of ±0.5 °C and a resolution of 0.0625 °C and an operating range of –40 to 85 °C. The diameter is 17 mm and the thickness is 5 mm. All temperature loggers were factory calibrated and re-calibrated by the authors in a thick mixture of fresh crushed ice and water. Temperature data loggers were placed within the product, one in the corner of packaging and one in the middle, and one on the outside of the boxes to monitor the ambient temperature.

Figure 4. IButton DS1922L temperature loggers.

2.3 Sensory evaluation

The four groups of haddock loins were evaluated by the sensory panel at Matís on sampling days (Table 2). The main purpose of the sensory evaluation was to evaluate differences in quality deterioration and shelf life of the four groups of haddock. The Quantitative Descriptive Analysis (QDA), as introduced by Stone and Sidel (2004), and the Torry freshness score sheet (Shewan et al., 1953) were used to assess cooked samples. Twelve panellists participated in the sensory evaluation. They had all been trained according to international standards (ISO 8586, 1993); including detection and recognition of tastes and odours, use of scales and in development, and use of descriptors. The members of the panel have experience in using the QDA method and Torry freshness score sheet for haddock. The panel was trained in recognising sensory characteristics of the samples and describing the intensity of each attribute for a given sample using an unstructured scale (from 0 to 100). Most of the attributes were defined and described by the sensory panel during other projects on lean white fish (Sveinsdóttir et al., 2009). The sensory attributes were 26 and are described in Table 2.

All loins used for sensory evaluation were taken from similar positions at the bottom of the containers to account for influence of pressure from above weight on sensory characteristics. Portions weighing about 40 g were cut from the loins and placed in aluminium boxes coded with three-digit random numbers. The samples were cooked for 6 minutes in a pre-warmed oven (Convotherm Elektrogeräte GmbH, Eglfing, Germany) at 95–100 °C with air circulation and steam, and then served warm to the panel. Each panellist evaluated duplicates of each test group in a random order in six sessions (maximum four samples per session). A computerised system (FIZZ, Version 2.0, 1994-2000, Biosystèmes) was used for data recording.

The sensory program Panelcheck V1.3.2 (Nofima, Tromsø, Norway) was used to evaluate panel performance. The statistical program NCSS 2000 (NCSS, Utah, USA) was used to analyse difference between groups with ANOVA (glm) and Duncan´s test. Differences between groups were considered significant when $p < 0.05$. Results from each sampling day were treated as a separate data set.

Table 2. Sensory attributes for cooked haddock and their description

Sensory attribute	Short name	Scale anchors	Description of attribute
Odour			
sweet	o-sweet	none | much	Sweet odour
shellfish, algae	o-shellfish	none | much	Shellfish, characteristic fresh odour
vanilla / warm milk	o-vanilla	none | much	Vanilla, sweet heated milk
boiled potatoes	o-potatoes	none | much	Reminds of whole warm boiled potatoes
dishcloth	o-cloth	none | much	Reminds of a dishcloth (damp cloth to clean kitchen table, left for 36 h)
TMA	o-TMA	none | much	TMA odour, reminds of dried salted fish, amine
sour	o-sour	none | much	Sour odour, sour milk, spoilage sour, acetic acid
sulphur	o-sulphur	none | much	Sulphur, matchstick
Appearance			
colour	a-dark	light | dark	Sample surface. Light; white colour, Dark; yellowish, brownish, grey
heterogenous	a-hetero	homogenous | heterogenous	Sample surface. Heterogenous, discoloured, stains
white precipitation	a-prec	none | much	White precipitation on the sample surface
flakiness	a-flakes	none | much	The fish portion slides into flakes when pressed with the fork
Flavour			
salt	f-salt	none | much	Salty taste
metallic	f-metallic	none | much	Characteristic metallic flavour of fresh haddock
sweet	f-sweet	none | much	Characteristic sweet flavour of very fresh boiled haddock
pungent	f-pungent	none | much	Pungent flavour, bitter
sour	f-sour	none | much	Sour taste, spoilage sour
TMA	f-TMA	none | much	TMA flavour, reminds of dried salted fish, amine
off-flavour	f-off	none | much	Strengh of off-flavour (spoilage flavour /off-flavour)
Texture			
soft	t-soft	firm | soft	Evaluate how firm or soft the fish is during the first bite
juicy	t-juicy	dry | juicy	Dry; draws juice from the mouth
tender	t-tender	tough | tender	Evaluated after chewing several times
mushy	t-mushy	none | much	Mushy texture
meaty mouthfeel	t-meaty	none | much	Meaty texture, meaty mouthfeel, crude muscle fibers
astringent	t-astringent	none | much	Clammy texture, tannin (dry red wine)
rubbery	t-rubbery	none | much	Rubbery texture, springy

2.4 Microbial measurements

Two samples were analysed on each day of sampling. Muscle sample was cut from the loins and then minced together and 20 g weighed in 180 g of Maximum Recovery Dilutent (MRD, Oxoid) and blended in a Stomacher® Lab Blender 400 (Seward, UK) for 1 min to obtain 1/10 dilution. The remaining mince was used for total volatile bases (TVB-N) and trimethylamine (TMA) measurements.

Total viable psychrotrophic counts (TVC) and counts of H_2S-producing bacteria were evaluated on iron agar (IA) as described by Gram et al. (1987) with the exception that 1% NaCl was used instead of 0.5% with no overlay. Plates were incubated at 17 °C for 4–5 d. Bacteria forming black colonies on IA produce H_2S from sodium thiosulphate and/or cysteine. Cephaloridine Fucidin Cetrimide (CFC) agar was modified according to Stanbridge and Board (1994) and used for enumeration of presumptive pseudomonads. Pseudomonas Agar Base (Oxoid) with CFC Selective Agar Supplement (Oxoid) was used. Plates were incubated at 22 °C for 3 d. *Pseudomonas* spp. form pink colonies on this medium. In all the above counts surface-plating was used.

Counts of *Photobacterium phosphoreum* were obtained by a quantitative PCR method. Briefly, one ml of the tenfold diluted fish samples in MRD buffer was frozen at –20 °C for later DNA extraction. For the DNA extraction, the diluted samples were centrifuged at 11.000 x g for 7 min to form a pellet. The supernatant was discarded and DNA was recovered from the pellet using DNA isolation kit (ChemoBacter, Reykjavík, Iceland) in combination with KingFisher magnetic beads automatic DNA isolation instrument (Thermo Labsystems, Waltham, USA) according to the manufacturers´ recommendations. All PCR reactions were done using the Mx3005p instrument using ChemoBacter qPCR mastermix (ChemoBacter, Reykjavík, Iceland).

2.5 TVB-N and TMA measurements

The method of Malle and Tao (1987) was used for measurements of Total Volatile Base-Nitrogen (TVB-N) and Trimethylamine (TMA). TVB-N was measured by steam distillation (Struer TVN distillatory, STRUERS, Copenhagen) and titration, after extracting the fish muscle with 7.5% aqueous trichloroacetic acid solution. The distilled TVB-N was collected in boric acid solution and then titrated with sulphuric acid solution. TMA was measured in trichloroacetic acid (TCA) extract by adding 20 ml of 35% formaldehyde, an alkaline binding mono- and diamine, TMA being the only volatile and measurable amine.

2.6 Life cycle assessment

2.6.1 Goal and scope

The objectives of the LCA study is to assess the environmental impacts associated with the delivery of fresh fish from Iceland to the United Kingdom, using the different transport methods and container packages as described in this study. By doing a comparative LCA study on those different methods, manufacturers, consumers and retailers are given the opportunity to compare the environmental impacts which their production, products and transportation methods have on the environment.

2.6.2 Functional unit

The functional unit for this study has to be divided into two steps because of the different transport methods. Therefore, the functional unit is: a) 200 kg of fresh fish loins transported by a container ship to Grimsby, b) 200 kg of fresh fish loins transported by air freight to Grimsby. It has to be noted that there are 4 groups; two which will be transported by sea and two with air. In each group the containers and accessories are different.

2.6.3 System boundaries

System boundaries define process/activity (e.g. manufacturing, transport and waste), and the input and output materials that will be included in the analysis.

For this study, the system boundaries include all relevant processes, except the end use phase of the fish transported to the UK. This is done in order to save a considerable amount of time and because those impacts may not be relevant to this study. It should also be noted that the fishery of the fish considered to be transported is not accounted for, for the same reasons. The following stages were analysed: 1. Production of all packaging materials and all materials for accessories, 2. Domestic transportation, 3. Transportation to, and inside the United Kingdom, 4. Recycling/waste disposal, 5. Transport of the PE tub back to Iceland and reuse.

2.6.4 System description

The phases in the LCA study are divided into 4 groups as described in the study. All groups start with the production of the packaging materials, with raw material extraction and power output needed. In each group the containers are then transported by truck to Suðureyri where they are filled with fish and all relevant materials and accessories for each container. The filled container is again transported to Reykjavík harbour or Keflavík airport, whichever applies to each group. Upon arrival in the United Kingdom, the containers are transported to Grimsby where the fish is unloaded and the containers either recycled (EPS box) or transported back to Iceland and reused (PE tub).

2.6.5 Impact assessment method

The impact assessment method used for this study is the Eco-indicator 99, to quantify the impact categories chosen for this study. The impact categories considered are climate change, acidification, eutrophication, ecotoxicity and respiratory organics/inorganics.

In this study, we use end-point impact assessment method as is available in the Eco-indicator 99. End-point assessment revolves around the single score presented in the method. The single score gives points (Pt) which are indicators of ecological scarcity. The value of 1 Pt points represents 1/1000th of the early environmental load of one average European habitant.

Carbon footprint for each group is also calculated, using the CML baseline 2000 impact assessment method, which uses the mid-point approach. End-point methods provide more intuitive measures, but at the expanse of certainty, while mid-point methods have less uncertainty (Ministry of Housing, 2000).

2.6.6 Inventory analysis

The main purpose of an inventory analysis in the context of data collection is to identify and quantify the relevant input and output flows crossing the system boundaries of the study. Collected process data were fed into the SimaPro software that was used to calculate the inventory results for all groups. The following are considered to be inputs and outputs of processes:

- Input: The use of resources, raw materials, auxiliary materials, energy carriers and electricity.
- Output: Emissions to air, water and land as well as waste and by-products.

2.6.7 Container production

The containers considered in this study are the 12 and 5 kg EPS boxes, manufactured by Promens Tempra located in Hafnarfjörður, and the 40 kg PE tub manufactured by Promens located in Dalvík. All information on production and ingredients came from the two companies. The container production stage includes EPS and PE and other materials needed for the production of plastic containers, as well as the power consumption needed for the whole process.

2.6.8 Transport

The containers, along with other accessories needed to cool the product are transported from the production plants, located in Dalvík and Hafnafjörður, to Suðureyri where they are filled with fish and accessories. The containers are then transported to Keflavík airport or Reykjavík harbor, depending on group, and transported via air or sea to the United Kingdom, where the final destination is Grimsby. All data on transports were gathered from project managers and in-house knowledge on fuel consumption and vehicle types. Data from transport companies already existed for domestic and over sea transports. For truck transportation in the UK, Icelandic data was utilized and changed for local conditions.

2.6.9 Recycle and reuse

In this study, only the containers were accounted for recycle or reuse. The time limitations did not allow for a complete mapping of disposal scenarios for every component used. Creating such a scenario is highly time consuming and complicated. Therefore, only simple recycle/reuse scenarios were created for the PE tub and EPS boxes.

In the case of the PE tub, it is considered as reusable and is modelled as 100% recyclable loop, which gives positive environmental score against the materials needed for its production, therefore evening the score out. It will however be transported back to Iceland for reuse, increasing the environmental load on transportation.

In the case of the EPS boxes, both 5 kg and 12 kg, the recycling will take place in the UK. The transportation to the nearest recycling plant and the power needed to recycle are accounted for. The data for the process is however highly assumptive because it utilizes secondary data taken from the Ecoinvent database of Simapro.

3 RESULTS AND DISCUSSION

3.1 Temperature measurements

3.1.1 Ambient temperature

The ambient temperature during the total transport and storage of the four experimental groups is shown in Figure 5. Considerable ambient temperature fluctuations were measured until the experimental groups were delivered to Matís around 21 hour after packaging. The mean ambient temperatures during this period were 2.5–2.8 °C for all the groups except the Sea-Tub group (6.5 °C). The high ambient temperature measured for the Sea-Tub group can be explained by a few hours unchilled storage before transport to Reykjavík.

In order to simulate thermal load during loading, flight and unloading, the air transport simulation groups were stored at mean temperatures of 13.8 and 14.0 °C for 7.4 hours. This thermal load is not excessive with regard to the temperature conditions, which can be expected in air transport chains (Mai et al., 2012; Margeirsson 2012).

After the thermal load one day post-packaging, all the experimental groups were stored in the same air climate chamber at relatively homogeneous temperature, the mean temperature from day 2 to day 13 was 1.8–1.9 °C, however rising slowly from 0 °C on day 2 to around 3 °C on day 13. The ambient temperature profile during this period is slightly worse than can be expected in well controlled sea transport according to Margeirsson (2012), who reported on five different sea transport trials with mean ambient temperature ranging from –0.9 to 1.1 °C.

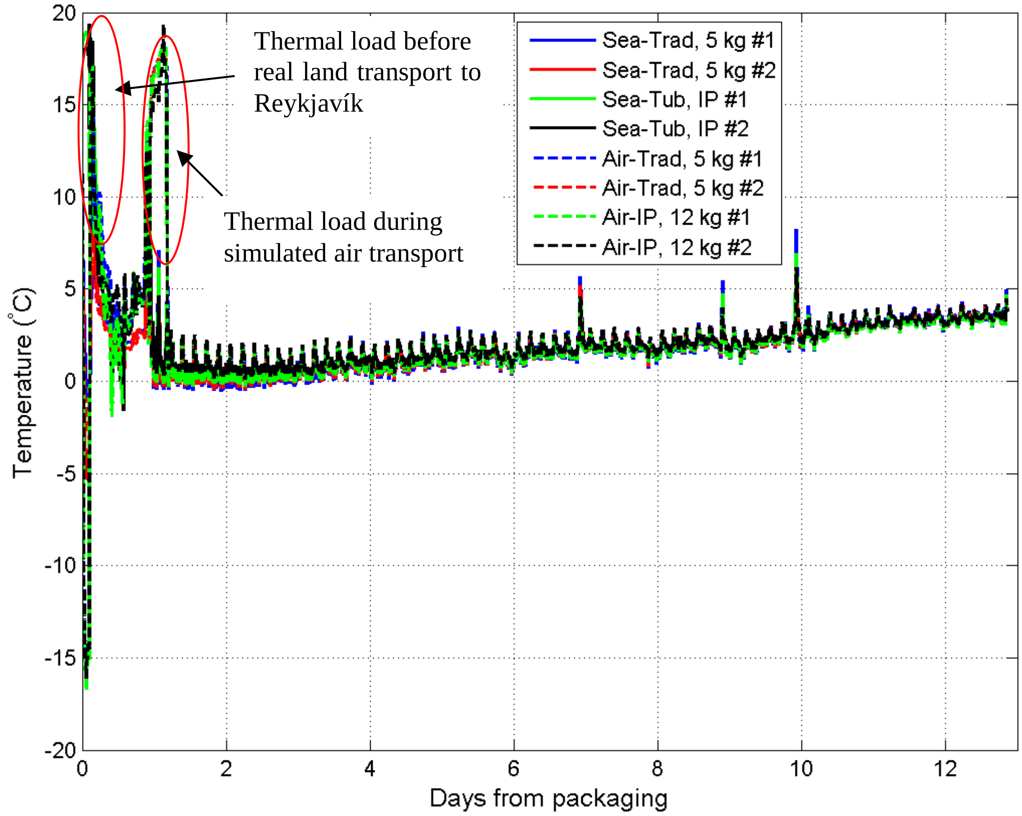

Figure 5. Ambient temperature profiles for the four experimental groups.

3.1.2 Product temperature

Different product temperatures were measured for the four experimental groups as is shown in Figure 6 (in middle of packaging), Figure 7 (in corners of packaging) and Table 3.

Table 3. Mean ambient and product temperature with ± one standard deviation during the specified storage period. Legends: Sea: simulated sea transport conditions, Trad: traditional packaging method, Air: simulated air transport conditions, IP: individually packed

Group	Ambient temperature (°C)	Product temperature in middle of packaging (°C)	Product temperature in corner of packaging (°C)	Period studied from packaging (days)
Sea-Trad, 5 kg	1.3 ± 1.1	1.5 ± 0.6	1.6 ± 0.7	9
Sea-Tub, IP	2.2 ± 2.2	0.0 ± 0.4	not measured	11.5
Air-Trad, 5 kg	1.9 ± 3.1	2.0 ± 0.8	2.0 ± 0.9	8
Air-IP, 12 kg	1.9 ± 3.7	2.3 ± 1.0	2.1 ± 1.0	7

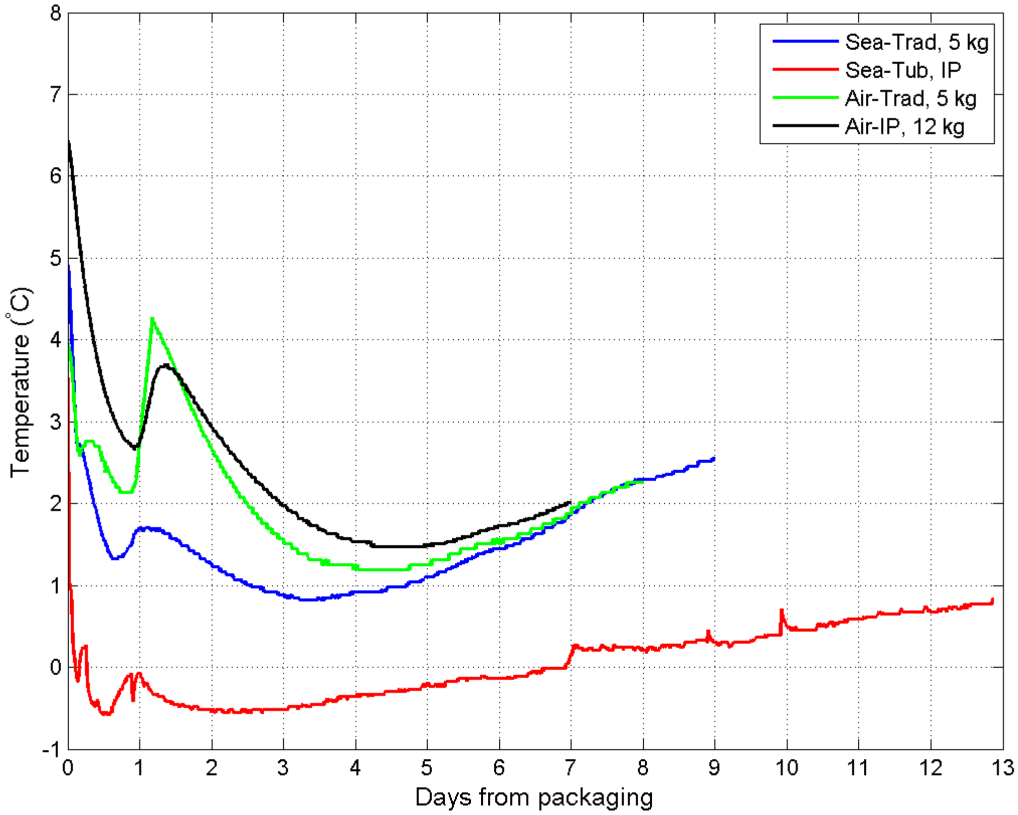

Figure 6. Product temperature in the middle of packaging calculated from two positions for each group.

The first thing to note is the lack of cooling during processing of the fish which is seen in fish temperatures between 3 and 7 °C at the time of packaging. This will inevitably decrease the storage life of the whitefish products as compared to products superchilled to around –1 °C during processing. The highest temperatures following packaging were measured in the vacuum-packed (IP) fish and half a day post packaging, the fish temperature in the middle of 12 kg Air-IP packages were still above 3 °C. The high temperature variations within the air transport packages measured in the current study are in good agreement with the results of Mai et al. (2012) and Margeirsson et al. (2011; 2012a,b,c) for both single packages and pallet stacks.

The Sea-Tub group was the only group with the fish temperature ever dropping below 0 °C, which in fact only required 2–4 hours post packaging. The slurry ice in the Sea-Tub substituted the lacking of precooling during processing, which is seen in the non-optimal fish temperature during packaging. Temperature of the fish in the other experimental groups remained above 1 °C during most of the storage. Comparison to the results of Mai et al. (2012) and Margeirsson (2012) thus implies that a lower, more suitable fish temperature could be expected for a well temperature controlled sea transport meaning that the Sea-Trad and Sea-Tub groups were not under optimal temperature control. In fact, independent of the too high ambient temperature in the air climate chamber simulating a containerised sea transport, the slurry ice in the tub should have contained a higher concentration of salt such that the slurry ice temperature would have been around –1 °C. This would probably have resulted in even longer storage life of the Sea-Tub group.

In conclusion, the product temperature control could be improved for all the experimental groups by efficient, superchilled processing and the sea transport groups were kept at non-optimal temperatures during the whole storage time.

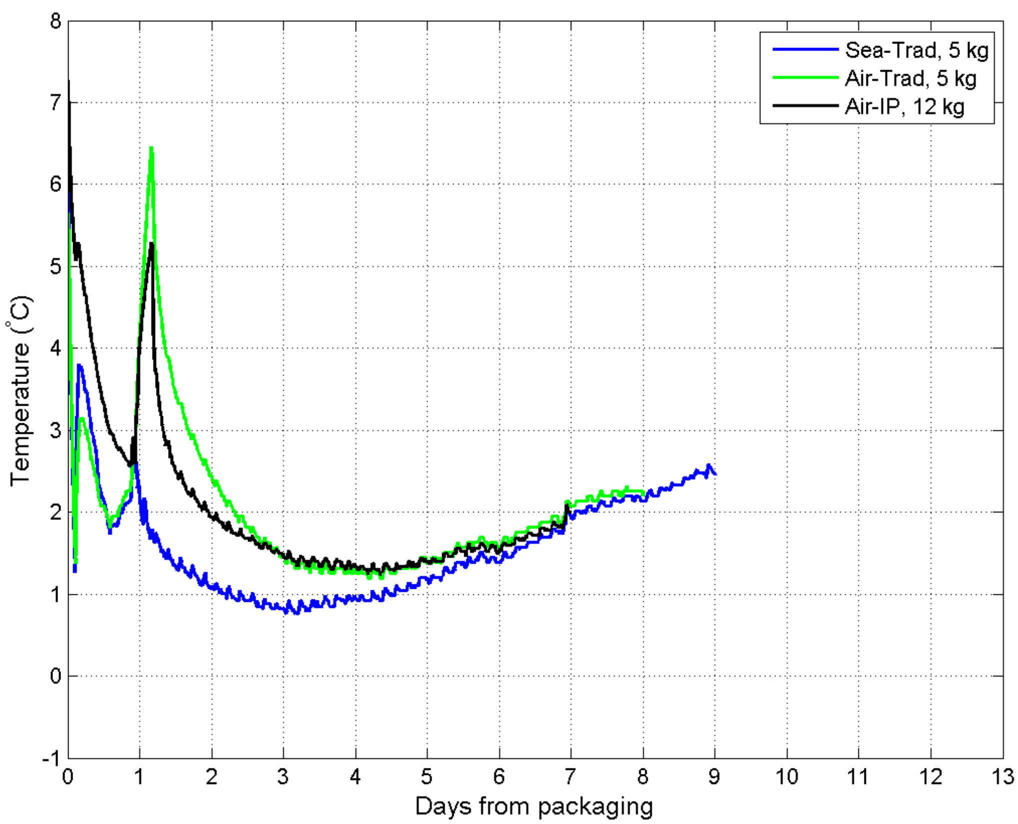

Figure 7. Product temperature in packaging corners calculated from two positions for each group.

3.2 Sensory evaluation

Sensory evaluation of cooked haddock was performed using two methods; Torry freshness assessment (Table A2 in appendix) and QDA method describing odour, appearance, flavour and texture of the sample groups (Table 2 in appendix). Results from QDA show no difference in texture attributes during storage time, indicating that pressure from above weight in the containers does not affect the texture of the loins significantly. Most of the difference in sensory characteristics between groups was related to different spoilage level (Figure 9 and Figure 10). Hardly any differences were seen between the two groups evaluated on day one post packaging, Sea-Tub and Air-IP. All four groups were evaluated on day seven. Group Air-IP, had more TMA odour than the other three groups and more sour odour than the sea transport groups. This indicates a higher level of spoilage in group Air-IP than in the other three groups. On day nine post packaging there were very big differences between groups in attributes relating to freshness and spoilage. Group Sea-Tub had a sweeter odour than both of the air transport groups and less dishcloth odour, TMA odour, sour odour and sulphur odour than the other three groups. Group Sea-Tub also had more metallic flavour and sweet flavour than the other three groups and less TMA flavour than the air transport groups. Group Air-Trad had more sour flavour and off-flavour than the sea transport groups. A difference was also seen in appearance on day nine. Group Sea-Tub had a lighter colour and a more homogenous colour than the other three groups. These results indicate a big difference in the level of spoilage between sample groups on day nine post packaging. Group Sea-Tub received higher scores for freshness related attributes than the other groups and lower scores for spoilage related attributes. These results are supported by results from Torry freshness assessment. Since all groups except group Sea-Tub, were no longer fit for consumption on day nine, only group Sea-Tub was evaluated on day 13.

Figure 8 shows how the Torry freshness score changes with storage time. One day post processing (packaging) the average Torry scores were 8.4–8.6. A Torry score around seven indicates that the fish has lost most of its freshness odour and flavour characteristics and has a rather neutral odour and flavour (Shewan et al., 1953). The time elapsed from processing until a Torry score of seven is reached is called the freshness period. This score was obtained after around 4–5 days for Air-IP, after 5–6 days for Air-Trad and around 7 days for the sea transport groups (Sea-Trad and Sea-Tub). However, because sensory evaluation was only performed on days 1 and 7 post packaging, the uncertainty in the freshness period estimation is high.

The results show that the Sea-Tub group retained freshness longer than the other three groups. When average Torry score has reached 5.5, the fish is no longer fit for consumption (Martinsdóttir et al., 2001). Difference in shelf life between groups Air-IP and Sea-Tub was around 4 days, see Table 4.

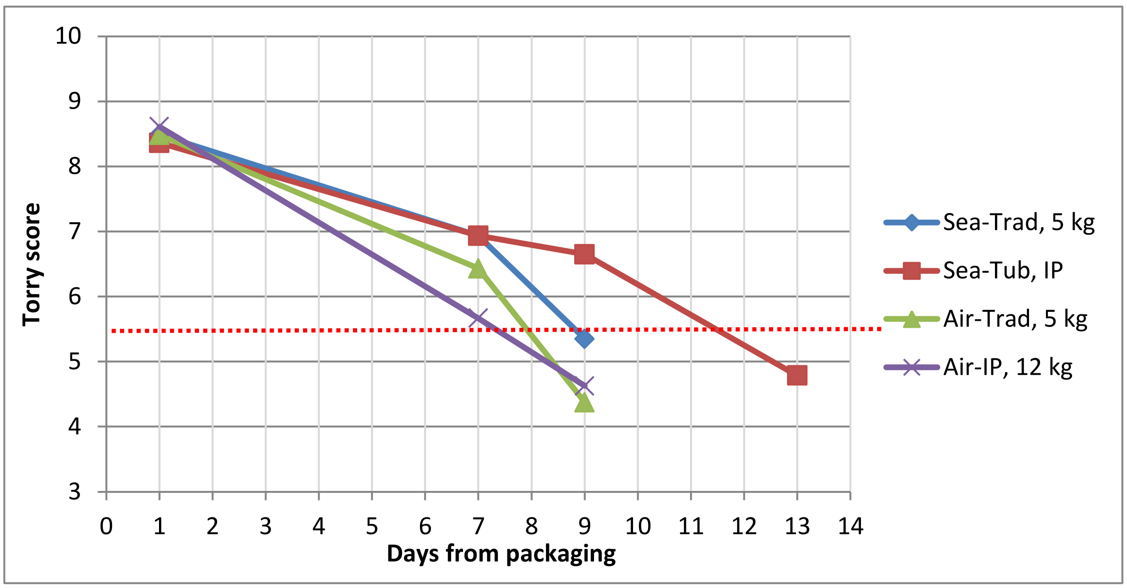

Figure 8. Average Torry freshness scores. Legends: Sea: simulated sea transport conditions, Trad: traditional packaging method, Air: simulated air transport conditions, IP: individually packed.

Table 4. Storage life according to sensory evaluation. Legends: Sea: simulated sea transport conditions, Trad: traditional packaging method, Air: simulated air transport conditions, IP: individually packed.

Group	Storage life (days)
Sea-Trad, 5 kg	8–9
Sea-Tub, IP	11–12
Air-Trad, 5 kg	7–8
Air-IP, 12 kg	7

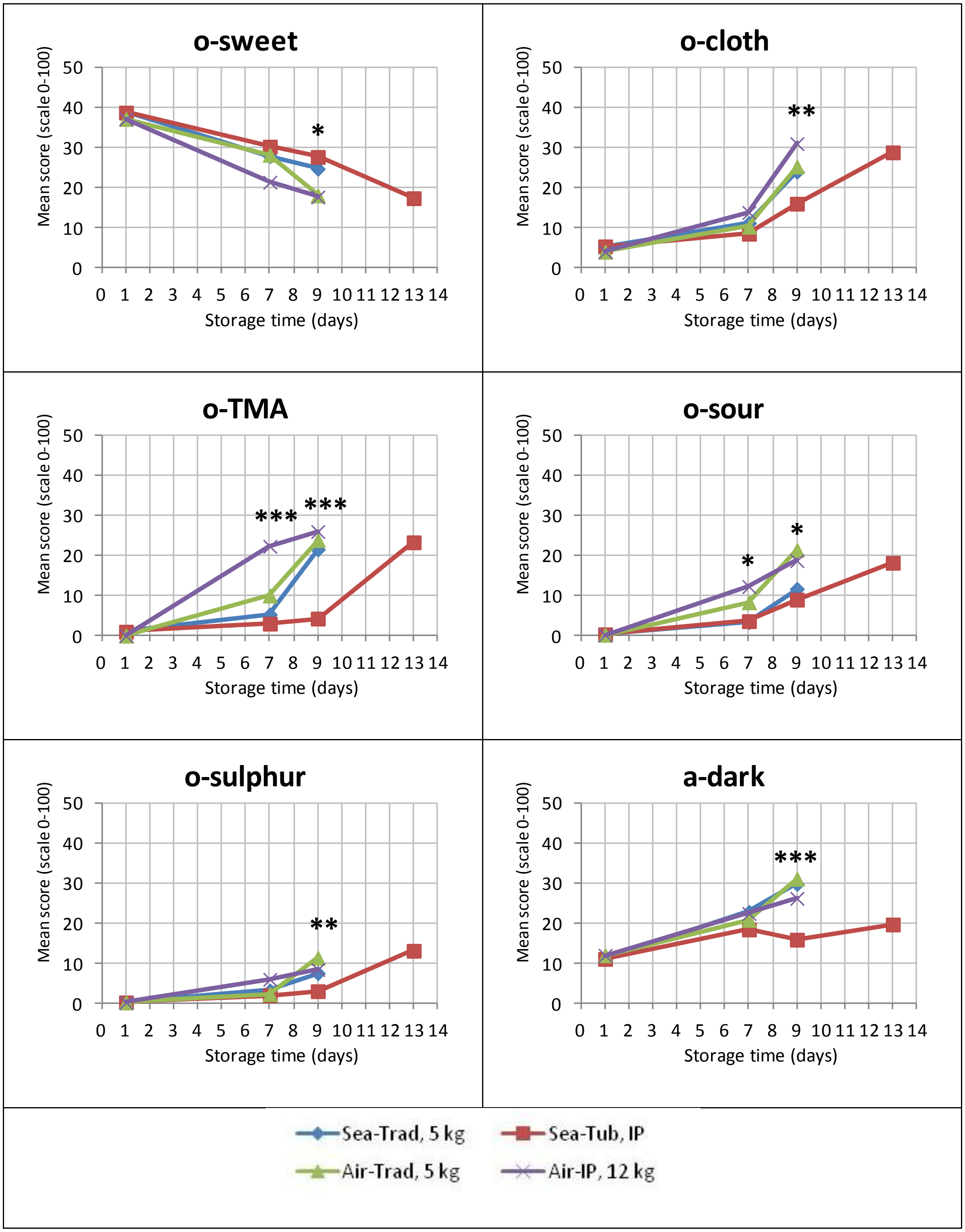

Figure 9. Mean scores for freshness and spoilage attributes showing differences between the four sample groups. (ms p < 0.10; * p < 0.05; ** p < 0.01; *** p < 0.001.)

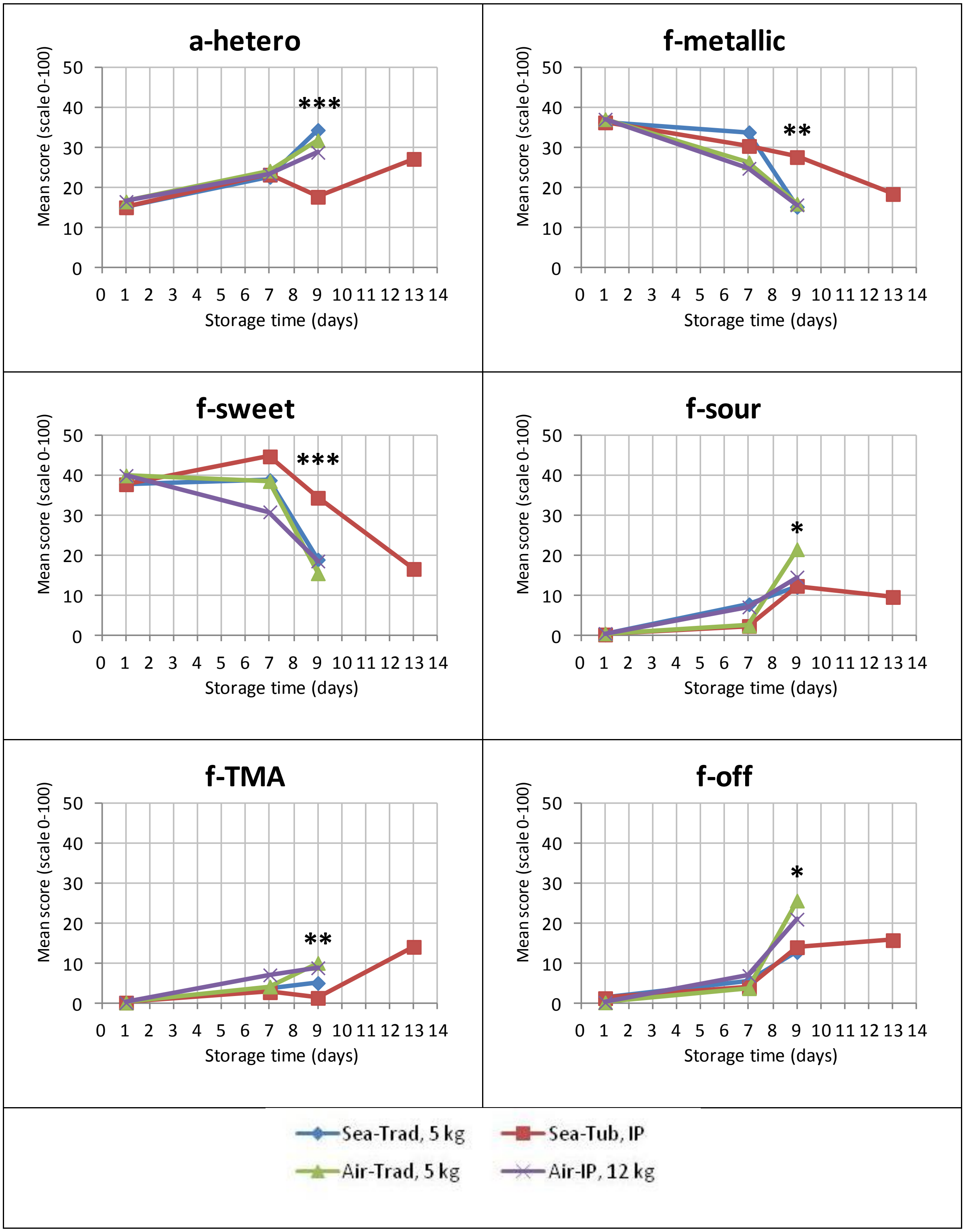

Figure 10. Mean scores for freshness and spoilage attributes showing differences between the four sample groups. (ms p < 0.10; * p < 0.05; ** p < 0.01; *** p < 0.001.)

The results from this storage study are in good agreement with the results of earlier storage studies applying storage temperatures between 0 °C and 2 °C reported by Lauzon et al. (2010a). The differences in storage life obtained in the current study can, in general, mostly be related to differences in the time-temperature history between the experimental groups.

3.3 Microbial measurements

Microbial analysis showed in all cases lowest counts in the Sea-Tub group and generally smaller difference between the other three groups. Analysis of total bacterial counts showed that number of bacteria on the first day of storage was 4.6 log CFU/g. Total bacterial growth was slow in the Sea-Tub group showing only a 0.6 log increase after 7 days of storage whereas the total bacterial counts in the other experimental groups had increased from 2.4 to 3.0 log units after the same storage time. When looking at the specific spoilage bacteria similar trends are observed. *Shewanella* like bacteria (IA-black) grew from 1.8 log CFU/g to 6.3 after 13 day storage period for the Sea-Tub group while it only took 9 days to reach similar numbers in the other experimental groups. *Pseudomonas* was the only bacterial group analysed which was effectively slowed down by vacuum storage. The Air-IP group showed lower *Pseudomonas* counts than Sea-Trad and Air-Trad groups but all those three groups showed similar growth curves for total count and *Shewanella*. *Photobacterium phosphoreum* was least affected by the various storage conditions but as before, the Sea-Tub group showed the lowest counts. *Photobacterium phosphoreum* is able to grow without oxygen and therefore the vacuum treatment did not affect it. The Air-Trad group showed however about 0.5 log CFU/g less growth after 7 and 9 days of storage than the Sea-Trad and Air-IP groups which cannot be easily explained. However, this bacterium can grow well in anoxygenic conditions, explaining the high numbers in the vacuum packed Air-IP group.

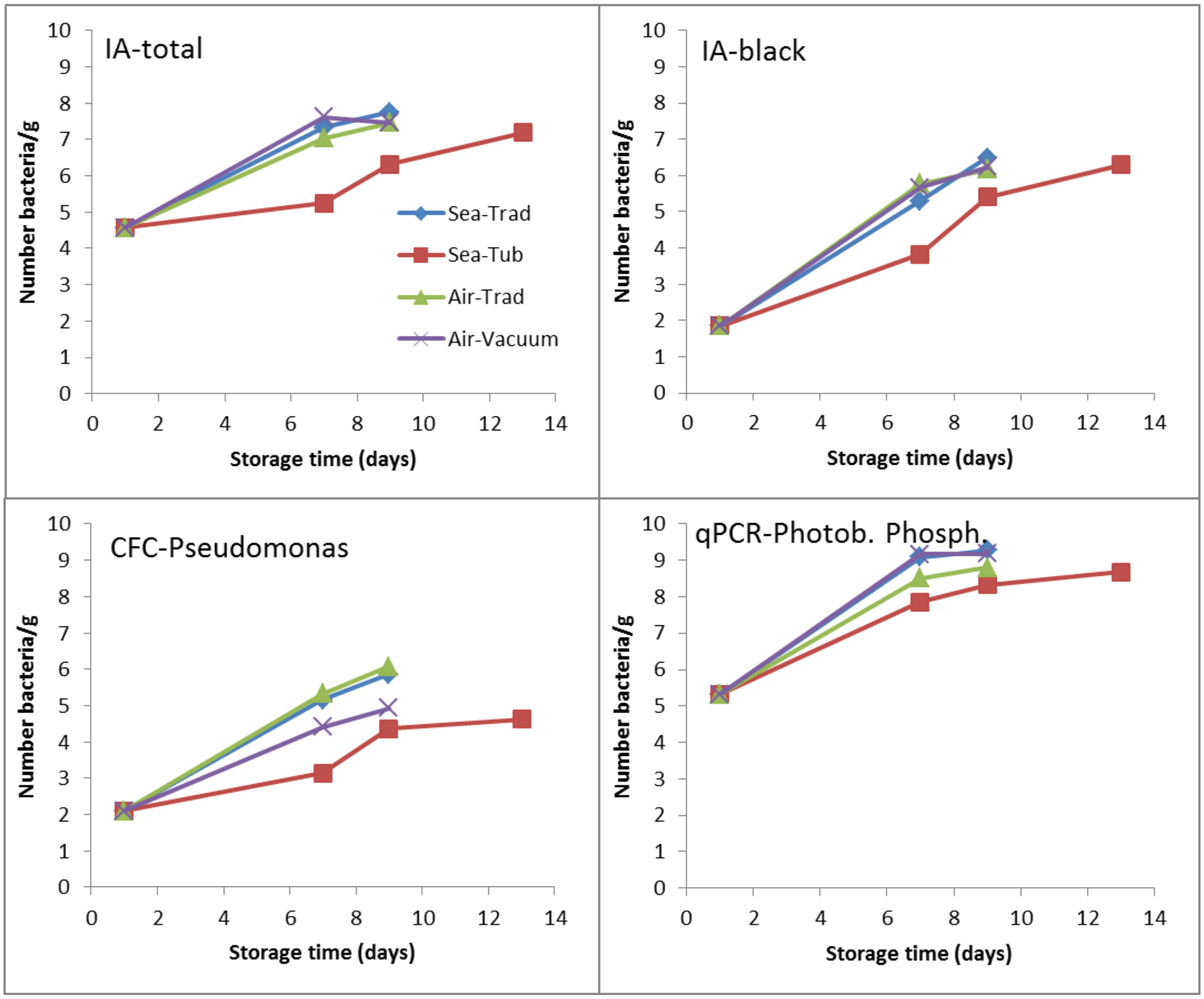

Figure 11. Total psychrotrophic viable counts (top, left), H_2S-producing bacteria counts (top, right) and pseudomonas (bottom, left) in haddock loins (evaluated by conventional methods) and *Photobacterium phosphoreum* counts estimated by PCR method (bottom, right) in cod loins. Legends: Sea: simulated sea transport conditions, Trad: traditional packaging method, Air: simulated air transport conditions, IP: individually packed.

3.4 TVB-N and TMA measurements

TVB-N and TMA content measured 13 days post packaging in the two sea transport groups is illustrated in Figure 12. Considerably lower values were obtained in samples from the tub group for both TVB-N and TMA. The lower TVB-N and TMA values observed in the tub-group are in agreement with slower spoilage bacteria growth in this group.

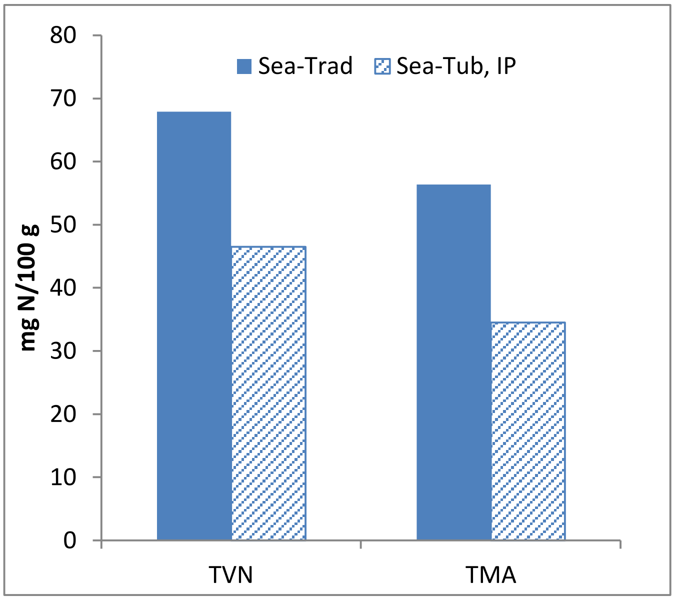

Figure 12. Total volatile base nitrogen (TVB-N) and trimethylamine (TMA) formation in haddock loins measured 13 days post packaging. Legends: Sea: simulated sea transport conditions, Trad: traditional packaging method, IP: individually packed.

3.5 Life cycle analysis

The results of this study are the findings from the analysis and calculations of data coming from various sources connected to this work. Because of time limitations, and because all data cannot be gathered, some assumptions had to be made. It is highly important to keep that in mind when viewing the final results, because they might be subjective to some extent. However the study was conducted as stated in the ISO 14040 series, and should give a very good idea how the processes look. With extended time frame a full scale LCA could be made with even more accurate results for selected projects.

The results show the single-score comparison between all groups, both with recycling/reuse and without it. In addition, groups Sea-Tub and Air-Trad are analysed further because they are the most and least contributing groups when considered with recycle and reuse.

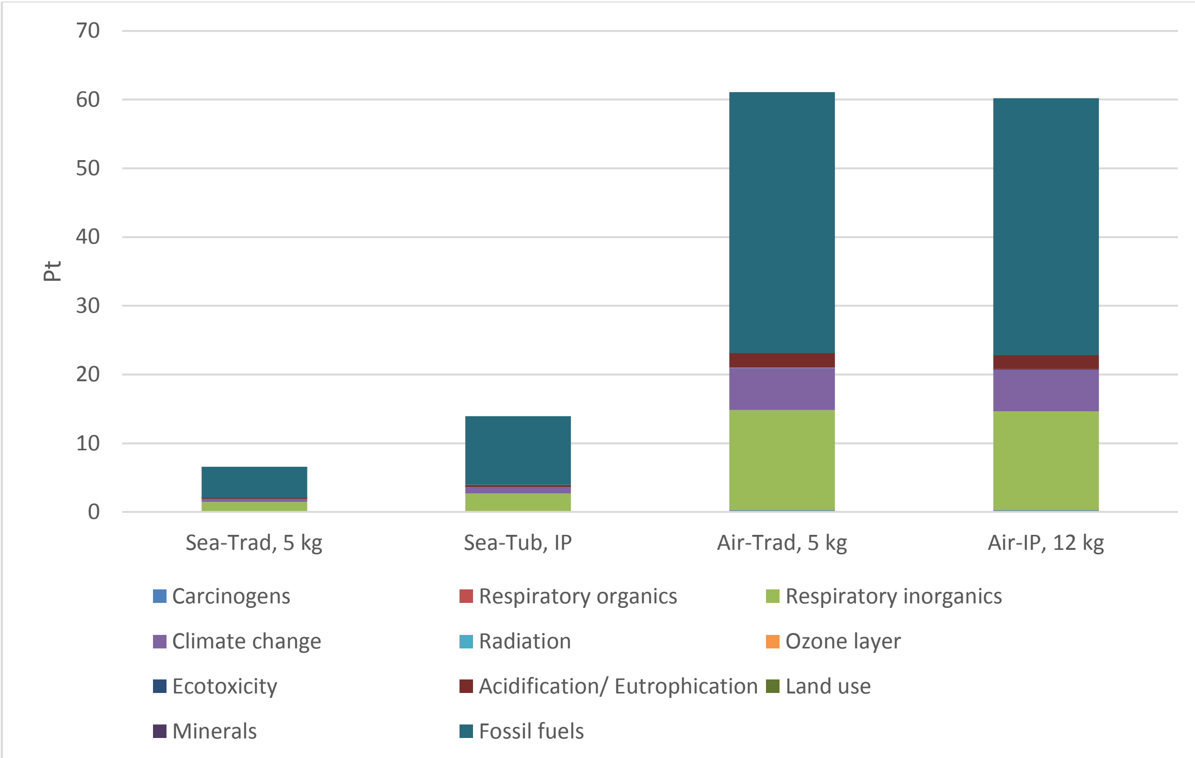

Figure 13. Comparison of all groups with single-score excluding reuse/recycle.

Figure 13 shows that the air transport groups dominate, with only slight variance. This is simply because of the air freight, which has a huge environmental load, compared to sea freight. The most dominating impact categories are fossil fuels (blue) and respiratory inorganics (grey).

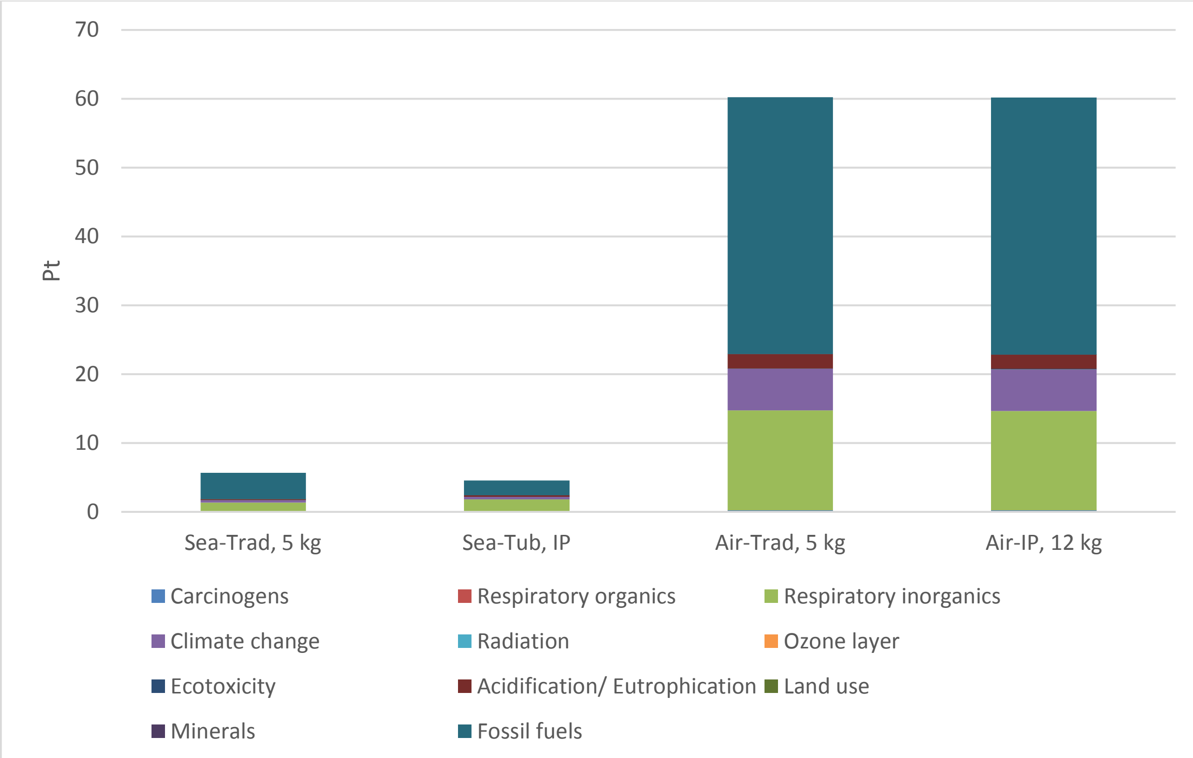

Figure 14. Comparison of all groups using single-score including recycle/reuse.

In Figure 14 the recycling and reuse phase has been added. That is, the EPS boxes in groups 1, 3 and 4 are recycled in the United Kingdom, and the PE tub is transported back to Iceland and reused. It can be seen that this lowers the environmental load on Sea-Tub considerably, making it the lowest scoring group. For the rest of the groups, the environmental load decreases to some extent, but fails to have any real impact with the air transport groups because of the high load of the air freight.

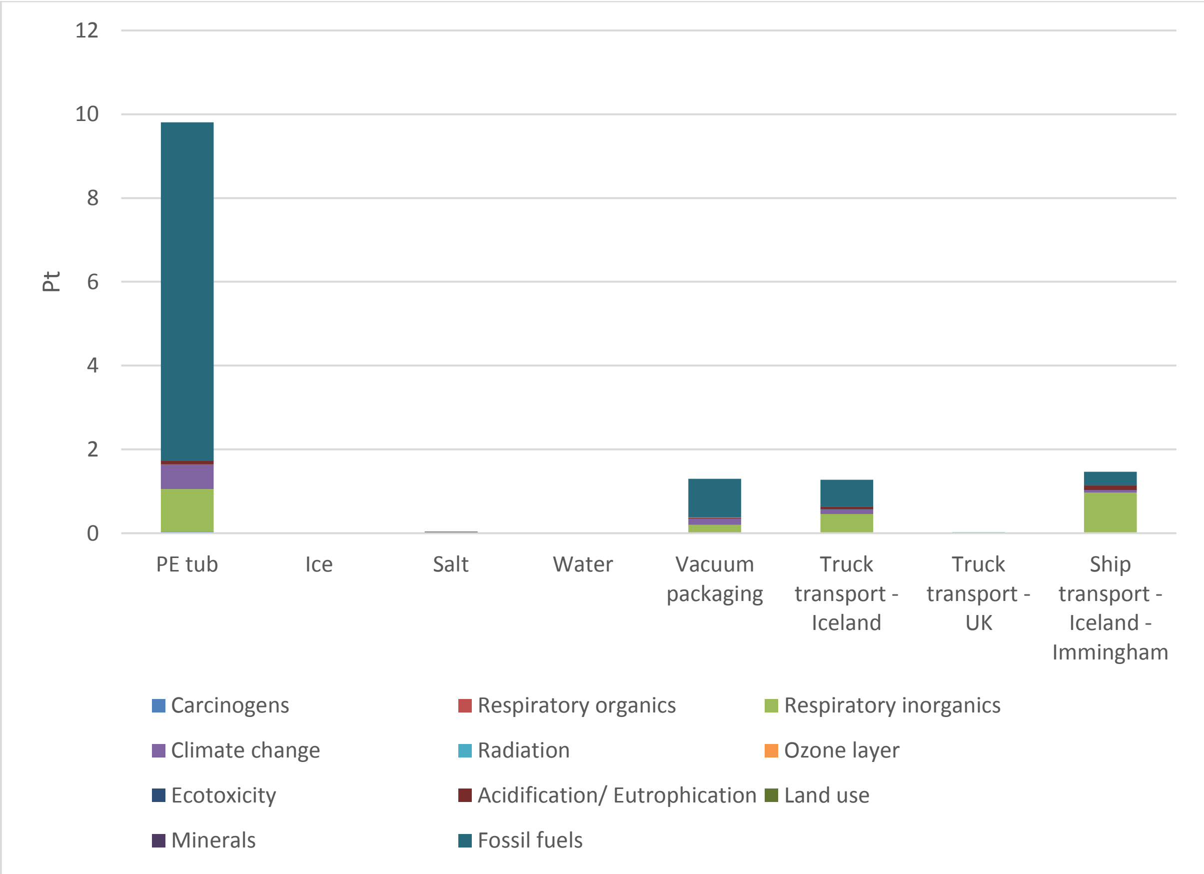

Figure 15. Single score for all phases for Sea-Tub.

When taking the recycle/reuse models into account, groups Sea-Tub and Air-Trad are the least and most contributing ones. In Figure 15 all phases of Sea-Tub can be further analysed. It should be noted that the reuse phase is not included because that would almost even out the production of the PE tub, which has the heaviest environmental load. It is interesting to see that the transport phases in Sea-Tub do not even match the production of the PE tub.

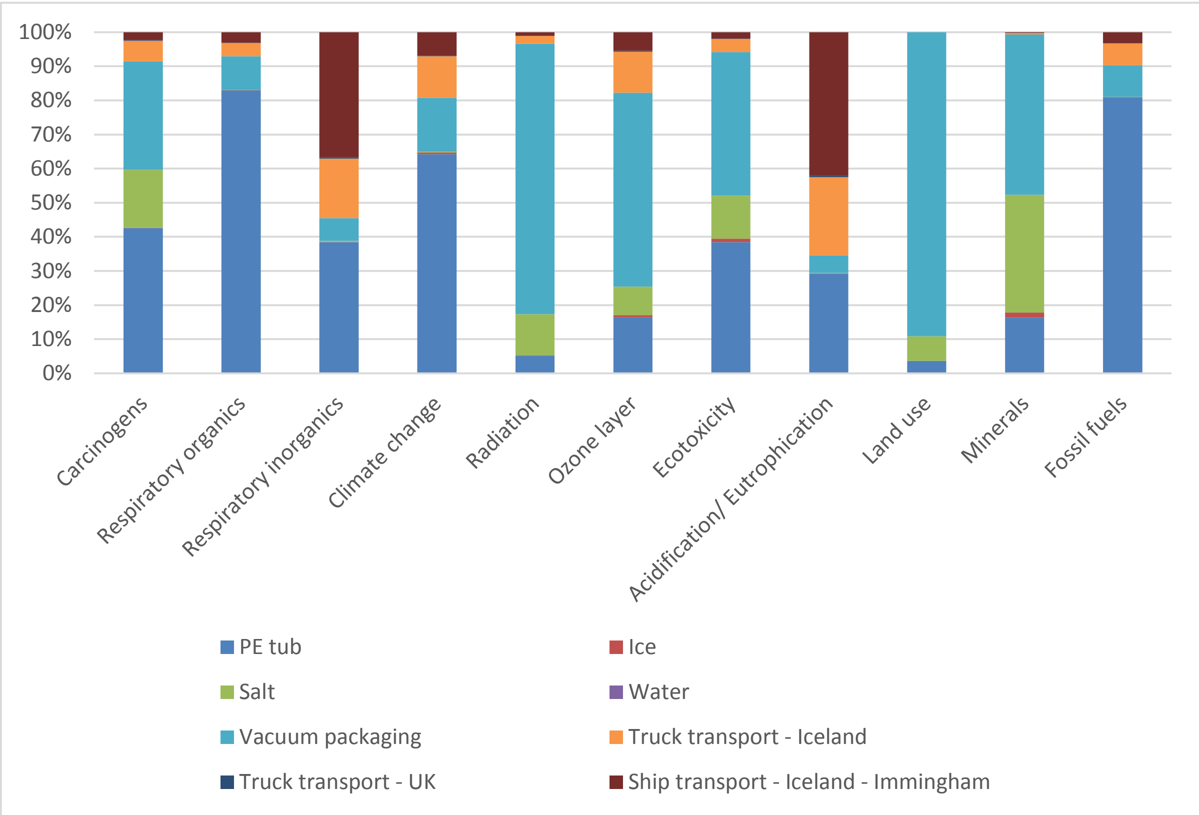

Figure 16. Characterization for all stages for Sea-Tub.

Regarding the characterization model (Figure 16) it can be seen that the production of the PE tub is dominating when it comes to environmental impacts, with the vacuum packaging following closely.

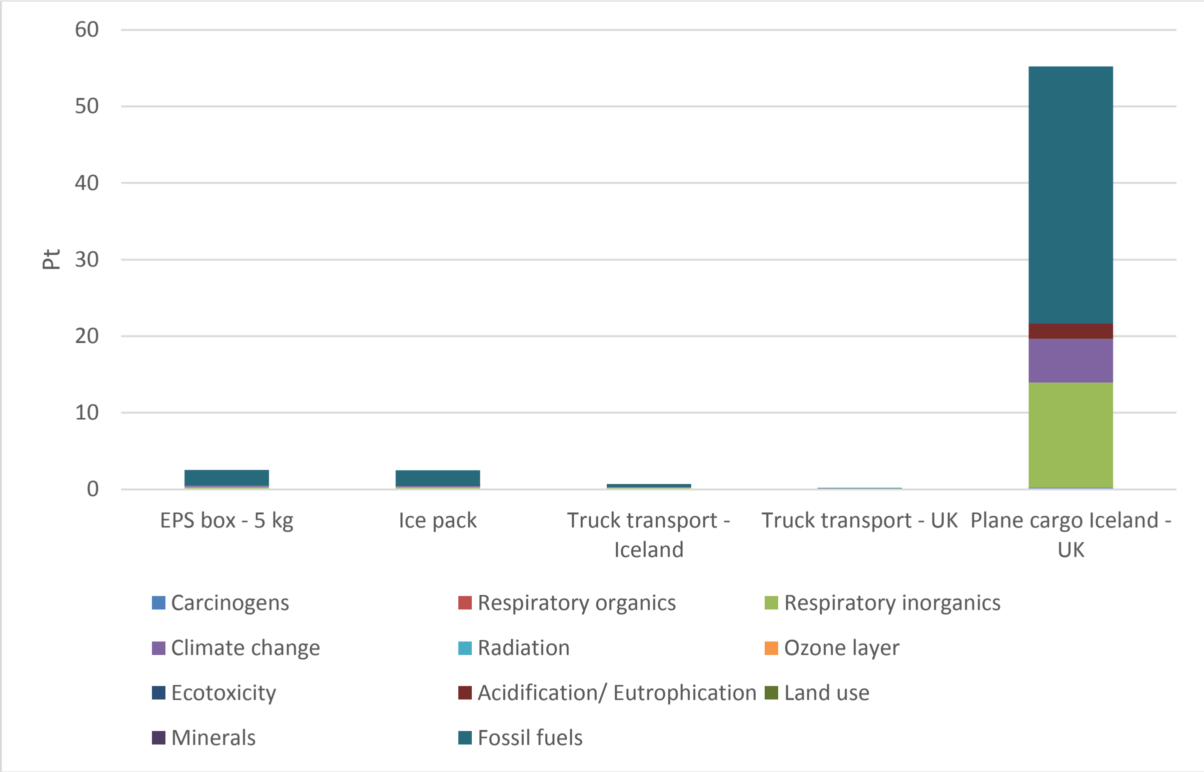

Figure 17. Single score for all phases for Air-Trad.

When looking at Air-Trad in more details (Figure 17), the air freight phase is contributing to such huge amounts that other phases seem negligible. With the fuel consumption of the air freight, impact categories such as fossil fuels and respiratory inorganics dominate.

Again, with the characterization, the air freight phase is dominating almost every group of impact categories (Figure 18). The production of the EPS box and ice packs come in second, but only with a fraction of the air freight phase.

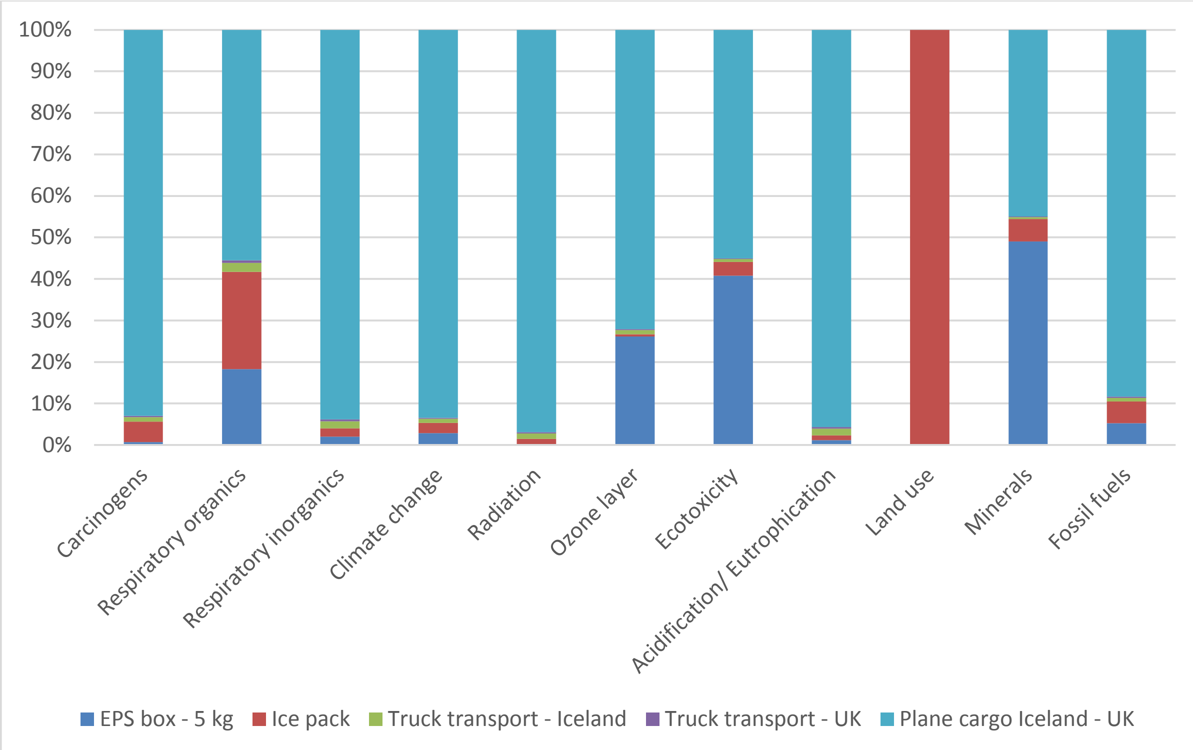

Figure 18. Characterization for all phases of Air-Trad.

3.5.1 Carbon footprint

Carbon footprint is defined as the total amount of carbon dioxide and other greenhouse gas emissions emitted over the full life cycle of a product or product system. It is measured in equivalent kilograms or tons of CO_2. The carbon footprint was calculated for each group, taking into account the recycling and reuse-phases of the containers.

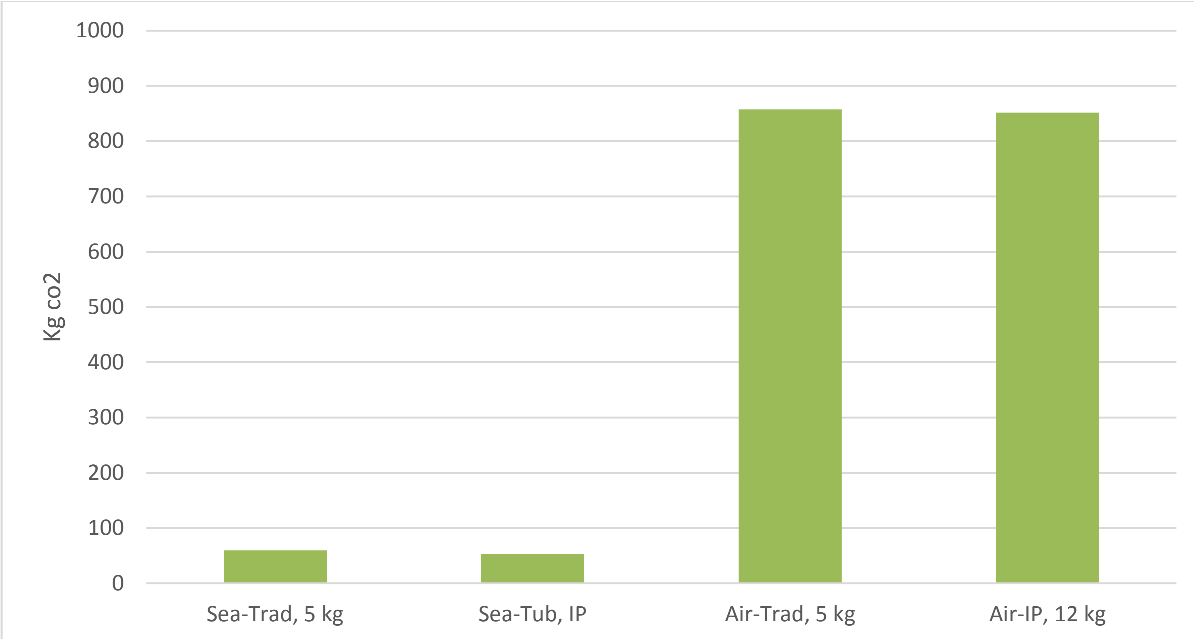

Figure 19. Carbon footprint of each group showed in kg CO_2

Unit	**Group 1**	**Group 2**	**Group 3**	**Group 4**
kg CO_2 eq	60	53	857	852

The calculation of carbon footprint shows that Sea-Tub scores the lowest number, only 53 kg CO_2 for the whole process. The air transport groups are almost equal in terms of CO_2, again, because of the dominance of the air freight phase.

4 CONCLUSIONS

The main conclusions from this study are that vacuum packed haddock loins immersed in slurry ice in a fish tub retained freshness longer than all the other experimental groups. The differences in storage life can mostly be related to temperature differences between the groups and ranged from 3 to 4 days between the best group (Sea-Tub) on one hand and the other groups on the other hand. Interestingly, the Sea-Tub group had around 3 days longer storage life than the Sea-Trad group with haddock loins packed in EPS boxes with an ice pack on top of the loins, and stored at similar temperature conditions simulating containerised sea transport. However, this difference would have been lesser if the ambient temperature for the Sea-groups had been lower, thereby minimising the importance of the cooling capacity and insulation of the slurry ice and the insulated tub walls. In general, good agreement was obtained between microbial- and sensory analysis and finally, the Life Cycle Assessment revealed that the Sea-Tub group has the least environmental impact.

Future work could include calculation of the volume efficiency of sea containers (tubs vs. EPS- or other wholesale packaging loaded on pallets). Furthermore, the usage of slurry ice in the Sea-Tub group could be optimised with regard to product temperature control and volume efficiency of the tub (ratio of fish to slurry ice) and finally, a more thorough Life Cycle Assessment could be conducted.

5 ACKNOWLEDGEMENTS

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7 APPENDIX

Table A1. Scheme for Torry freshness evaluation of cooked cod

Odour	Flavour	score
Initially weak odour of sweet, boiled milk, starchy followed by strenghthening of these odours	Watery, metallic, starchy. Initially no sweetness but meaty flavours with slight sweetness may develop	**10**
Shellfish, seaweed, boiled meat	Sweet, meaty, characteristic	**9**
Loss of odour, neutral odour	Sweet and characteristic flavours but reduced in intensity	**8**
Woodshavings, woodsap, vanillin	Neutral	**7**
Condensed milk, boiled potato	Insipid	**6**
Milk jug odours, boiled clothes- like	Slight sourness, trace of off-flavours	**5**
Lactic acid, sour milk, TMA	Slight bitterness, sour, off-flavours, TMA	**4**
Lower fatty acids (eg acetic or butyric acids) composed grass, soapy, turnipy, tallowy	Strong bitter, rubber, slight sulphide	**3**

Table A2. Mean values for all sensory attributes and p-values for difference between groups. Different letters within a column and storage day indicate statistically significant difference between the relevant groups.

Group	o-sweet	o-shellfish	o-vanilla	o-potatoes	o-cloth	o-TMA	o-sour	o-sulphur	a-dark	a-hetero	a-prec	a-flakes
Day 1												
Sea-Tub, IP	39	29	15	8	5	1	0 **a**	0	11	15	30 **b**	63
Air-IP, 12 kg	37	27	18	7	4	0	0 **b**	0	12	17	38 **a**	56
p-value	0,445	0,475	0,301	0,733	0,184	0,270	0,007	1,000	0,472	0,546	0,006	0,054
Day 7												
Sea-Trad, 5 kg	28	21	14	10	11	5 **b**	3 **b**	3	23	23	36	52
Sea-Tub, IP	30	21	12	9	9	3 **b**	4 **b**	2	19	23	38	46
Air-Trad, 5 kg	28	18	16 **a**	10	10	10 **b**	8	2	21	24	37	54
Air-IP, 12 kg	21	17	8 **b**	14	14	22 **a**	12 **a**	6	23	23	31	53
p-gildi	0,148	0,495	0,032	0,175	0,363	0,000	0,020	0,051	0,630	0,974	0,066	0,253
Day 9												
Sea-Trad, 5 kg	25	16	11	15	24 **a**	22 **a**	12	8	30 **a**	34 **a**	31	53
Sea-Tub, IP	28 **a**	20	12	15	16 **b**	4 **b**	9 **b**	3 **b**	16 **b**	18 **b**	36	50
Air-Trad, 5 kg	18 **b**	14	9	14	25 **a**	24 **a**	21 **a**	11 **a**	31 **a**	32 **a**	30	52
Air-IP, 12 kg	18 **b**	14	10	12	31 **a**	26 **a**	19	9	26 **a**	29 **a**	30	54
p-gildi	0,013	0,083	0,627	0,718	0,002	0,000	0,020	0,008	0,000	0,000	0,261	0,766
Day 13												
Sea-Tub, IP	17	18	15	17	29	23	18	13	20	27	29	39

Group	f-salt	f-metallic	f-sweet	f-pungent	f-sour	f-TMA	f-off	t-soft	t-juicy	t-tender	t-mushy	t-meaty	t-astringent	t-rubbery
Day 1														
Sea-Tub, IP	12	36	38	4	0	0	1	58	66	63	21	25	13	13
Air-IP, 12 kg	11	37	40	3	1	0	0	53	67	61	17	27	15	13
p-value	0,706	0,761	0,409	0,804	0,265	1,000	0,311	0,300	0,766	0,619	0,083	0,499	0,399	0,907
Day 7														
Sea-Trad, 5 kg	14	34	39	4	8	4	6	57	65	63	22	19	17	11
Sea-Tub, IP	15	30	45	5	2	3	4	54	63	63	20	18	19	8
Air-Trad, 5 kg	14	26	39	6	3	4	4	54	61	58	22	19	14	15
Air-IP, 12 kg	15	25	31	6	7	7	7	59	60	66	20	13	13	7
p-gildi	0,667	0,123	0,266	0,557	0,600	0,406	0,821	0,602	0,487	0,303	0,954	0,219	0,108	0,143
Day 9														
Sea-Trad, 5 kg	15	15 **b**	19 **b**	13	12 **b**	5	13 **b**	49	50	51	29	20	15	9
Sea-Tub, IP	16	28 **a**	34 **a**	11	12 **b**	1 **b**	14 **b**	54	56	61	27	26	19	9
Air-Trad, 5 kg	13	16 **b**	16 **b**	14	22 **a**	10 **a**	26 **a**	56	52	56	32	19	16	10
Air-IP, 12 kg	14	16 **b**	19 **b**	11	15	9 **a**	21	48	48	51	23	21	15	8
p-gildi	0,252	0,008	0,000	0,735	0,036	0,005	0,011	0,361	0,169	0,089	0,303	0,337	0,376	0,876
Day 13														
Sea-Tub, IP	15	18	17	13	10	14	16	61	55	59	30	24	23	21