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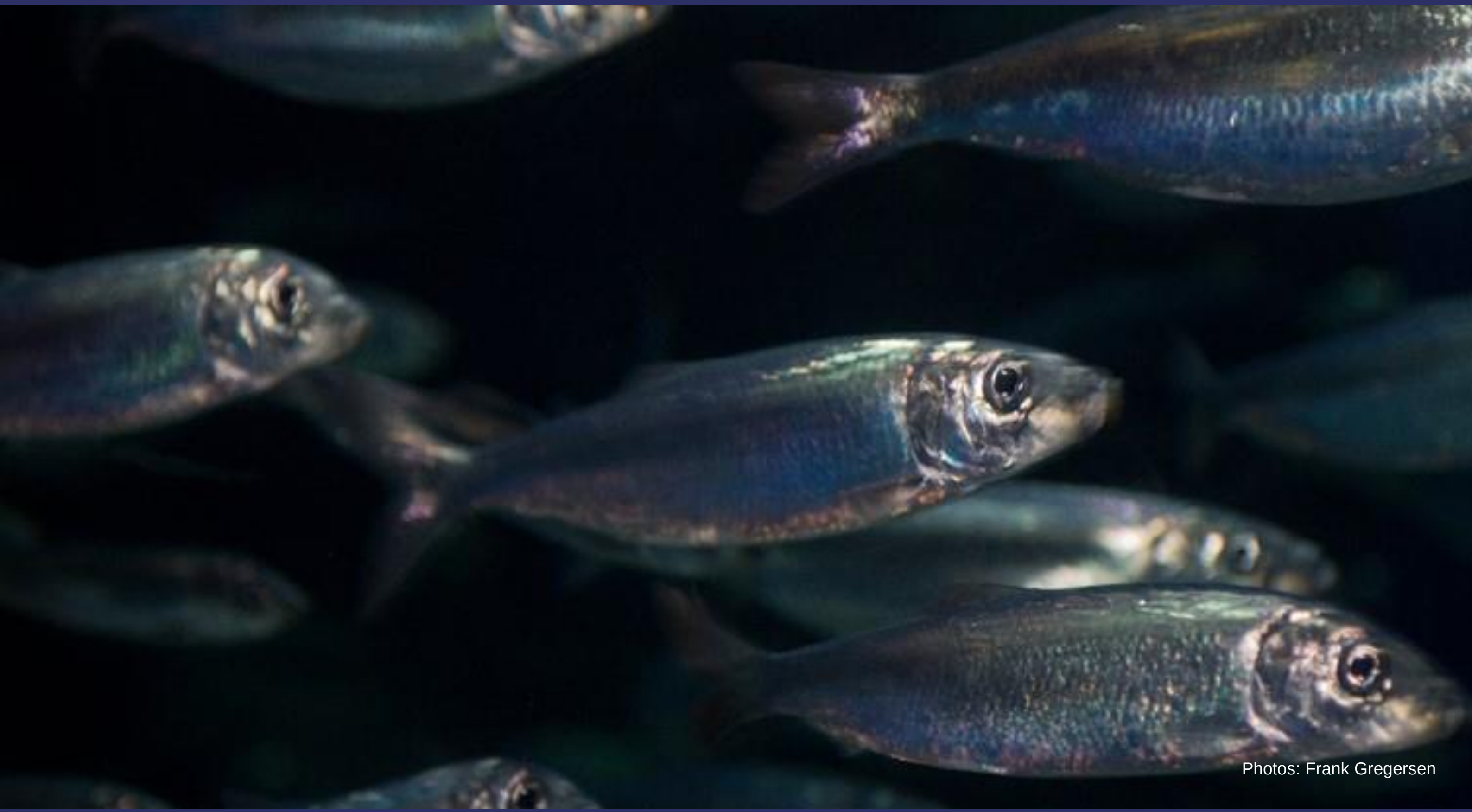
The salt content in herring

How the salt content in herring changes during capture and catch handling



Photos: Frank Gregersen

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Title:

Salt content in herring – How the salt content in herring changes during capture and catch handling

Tittel:

Saltinnhold i sild – Hvordan saltinnholdet i sild kan endres under fangst og fangsthåndtering

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Brazil applies a threshold limit value for the amount of salt that is accepted in natural herring, namely 134 mg sodium per 100 g fillet. Compared with the salt content values found in the relevant literature, and the measurements that are routinely performed in Norway, this is a low value that would be difficult to fulfil. RSW (Refrigerated Sea Water) is a quick and appropriate agent for chilling large catches – of herring, for example. However, when fish are stored in RSW after capture, they may assimilate salt from the cooling medium.

Another factor that can increase the salt content in herring is stress. When herring are subjected to stress, as happens during capture, the salt content in their blood will increase. All in all, the threshold limit value set for salt content in Brazil is considered to be unrealistically low, taking into account how catches are handled in Norwegian pelagic fisheries.

* The original report is in Norwegian and the reference is: 8/2023, ISBN 978-82-8296-743-3

Sammendrag på norsk:

I Brasil er det satt en grenseverdi for hvor mye salt som aksepteres i naturell sild, 134 mg natrium per 100 g filet. Sammenlignet med verdier for saltinnhold som finnes i litteraturen, og målinger som er gjennomført rutinemessig i Norge, er denne verdien lav og vil vanskelig kunne etterleves. RSW (kjølt sjøvann) er en hurtig og hensiktsmessig kjølemetode for store fangster slik som sild. Men, dersom fisken lagres i RSW etter fangst, kan den ta opp salt fra kjølemediet.

En annen faktor som også kan øke saltinnholdet i sild, er stress. Dersom silda påføres stress, slik som skjer under fangst, vil saltkonsentrasjonen i blodet øke. Samlet sett synes det som om grenseverdien for saltinnhold satt i Brasil, er urealistisk å oppnå med tanke på hvordan fangsten håndteres i norske pelagiske fiskerier.

* Den originale rapporten er på norsk og referansen er: 8/2023, 978-82-8296-743-3

Abbreviations

CSW – Chilled Sea Water

TVB-N – Total Volatile Basic Nitrogen

Na^+ – Sodium

NaCl – Common salt (Sodium chloride)

NSS - Norwegian Spring-Spawning

IMR - Institute of Marine Research

RFW – Refrigerated Fresh Water

RSW – Refrigerated Sea Water

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1 Introduction

This is a translation of Report 8/2023, ISBN 978-82-8296-743-3

Atlantic herring (Clupea *harengus*), also known as “the silver of the sea”, is an important resource in Norway. It is an important food fish, and large proportions of the catches landed are exported (Norges Sjømatråd, 2023; Pethon & Nyström, 2019). Brazil is one of the countries that import herring from Norway. However, exports to Brazil have encountered some challenges, primarily linked to salt content. In 2017 Brazil set a threshold limit value for salt, measured in volume of Na^+, of 134 mg/100 g natural fish. Norwegian exporters of herring and other pelagic species often experience salt content measurements in excess of 134 mg/100 g. When Brazilian authorities identify Na^+ content that exceeds the threshold limit value, the shipment must be either destroyed or returned. This threshold limit value is considered to be unrealistically low and creates problems for the export of herring and pelagic fish to Brazil, particularly whole round frozen natural herring. It is therefore necessary to examine literature and other documentation that presents the salt content in natural herring and explains how the salt content is affected by natural variations, capture and storage conditions.

This report focuses on the following:

- Natural salt content in live herring
- The osmosis regulation of herring during and after stress
- The impact of catch handling on salt content
- Methods for taking samples

2 Project execution

A literature review was initially performed to determine what had been documented in previous studies with regard to salt content in herring. The review encompassed both research reports and scientific articles. The Norwegian Institute of Marine Research, the Norwegian Seafood Federation and the Norwegian Fishermen's Sales Organization for Pelagic Fish (*Sildesalgslaget*) also provided relevant information.

Sildesalgslaget and Biolab contributed data from analyses of salt content in North Sea herring and Norwegian spring-spawning (NSS) herring conducted in Norway in the period 2018–22. In total, 868 samples were made available for this work and Microsoft Excel was used to process and visualise the data. Aspen Unscrambler™ version 11.0 was used to run a PLS (Partial Least Square Regression) analysis with the Martens Uncertainty Test (Martens & Martens, 2001) to establish whether the temperature in the raw material during unloading, the conservation method used on board, the size of the catch and the days spent stored in RSW influenced the salt content of the herring.

3 Salt content in herring

3.1 Natural variations in salt content

An advisory note from Torry Research Station (Murray & Burt,1969) includes a simplified summary of the chemical composition of more than 50 species of fish and shellfish that were landed in or imported into the UK. The average salt content for all the species is stated as **72 mg Na^+/100 g**, with a variation of **30 to 134 mg Na^+/100 g** fish. However, Murray & Burt (1969) emphasise that the stated mineral content should only be viewed as a rough guide, and that it cannot be considered a detailed analysis for separate species.

Sidwell et al. (1977) summarised data from 128 works on topics including the analysis of sodium in 161 common marine species. They demonstrated major variations in measured values within the same species, and reported that the salt content for herring was between **49 and 183 mg Na^+/100 g** fish, with mean value of **103 mg Na^+/100 g** fish. Sidwell et al. (1977) demonstrated that the great variations in sodium content can be attributed in part to the fact that different methods were used to determine the salt content, and that variations in the minerals can also be ascribed to age, size, gender and seasonal variations.

The Institute of Marine Research (IMR) performed analyses of the salt content in herring muscle (fillet) in 2020 (NIFES, 2023). They measured an average of **103 mg Na^+/100 g** herring fillet (N=121). The lowest measurement was **51 mg Na+/100 g** and the highest was **240 mg Na+/100 g**. This indicates that salt content can vary greatly between individual fish.

The fat content of fat fish will vary significantly during the year, and the fat content of herring is stated as varying between 0.4 and 30% (Murray & Burt, 1969; Sidwell et al., 1974; Sikorski, 1990; Slotte, 1999). The total of water and fat remains relatively stable, however, at around 80% throughout the year. As salt is soluble in water but not in fat, there will likely be appreciable variations in the amount of salt per 100 g fish depending on the season.

The salt content will also vary depending on where in the fish the sample is taken. For example, salt concentrations are higher in the head, around the gills and in those parts of the fish that contain little fat (Olsen et al., 2012; Tenningen et al., 2012; Wu et al., 2022).

3.2 Salt regulation in live herring

Fish demonstrate different strategies for handling the salt balance in the environment in which they live. Marine fish live in salt concentrations that are approximately three times higher than their internal salt concentration. Without mechanisms for keeping their internal salt concentration lower than that of their external environment, these fish could not survive.

When marine fish drink seawater, they assimilate sodium and chloride ions from the seawater into their blood through the oesophagus, from where they are transported to the gills for excretion back into the sea. Fish also breathe over their gills, and when fish increase their level of activity, their systems prioritise respiration over the excretion of salt. Once the period of increased activity is finished, the fish need time to recover and restore the water/salt balance by expelling superfluous salt ions. This increased level of activity can, for example, be caused by the stress fish experience in connection with their capture (Farrell, 2011).

4 Capture and catch handling – impact on salt content

As mentioned previously, there will be large natural variations in the salt content in herring, and the capture operation causes stress which, in turn, will affect the natural salt content in the fish body. Storage in seawater will likewise affect the salt content. If the fish are left lying in seawater long enough after they are dead, the internal salt concentration will gradually balance out with the surrounding medium, given that dead fish do not secrete salt into their surroundings. The salt concentration in the herring will thus approach that of the seawater over the course of the storage period.

4.1 Capture

4.1.1 Pelagic trawling

This form of trawling often lasts around two hours. If the shoal of fish is densely packed, the operation can be completed in 10–20 minutes, but if the fish are spread over a larger area, it can take up to five hours before the catch is pumped aboard (Burt et al., 1992; "Kvalitetshåndbok for pelagisk fisk," 2011). Observations indicate that during trawling for herring, the fish swim vigorously and that they collide with both the trawl net and the other fish. This results in the fish becoming stressed and exhausted. It also leads to scale loss and damage to the layer of mucus and skin (Olsen et al., 2012; Suuronen et al., 1996). Mortality rates are much higher during trawling than when purse seines are used. This is because the fish become exhausted from their attempts to escape from the trawl, and because the fish that are crushed together in the bottom of the trawl net have difficulty breathing if there is insufficient space for them to move their gills. Fish that die in the fishing gear in the early phase of the trawling operation can assimilate some salt before the trawling process is completed (Digre & Hansen, 2005). Both stress and damage to the fish skin/scales can affect the volume of salt and salt assimilation during storage.

4.1.2 Purse seines

When purse seines are used, the shoal of fish is surrounded by net before the bottom of the net is closed. This process is considered to be a much less harmful method for catching fish. The fish only become aware of the process when the net is pulled together to crowd the fish so that the catch can be pumped aboard easily and efficiently. How tightly the fish are crowded together – and for how long – depends on the size of the catch and the capacity of the vessel. When the fish are crowded together, they often become so tightly packed that the water around them becomes depleted of oxygen. This stresses the fish, and many of them die if the crowding phase is hard and lasts a long time. Hard and protracted crowding can cause significant scale loss among the fish. In the case of large catches, the crowding phase can last for over an hour. Observations of crowding indicate that mortality can commence after as little as 10 minutes (Huse & Vold, 2010; Tenningen et al., 2012; Tveit et al., 2017). In tests where herring were crowded in a net and then allowed to recover, blood samples revealed elevated levels of salt ions for several days after crowding (Tenningen et al., 2012).

Figure 1 Fishing with a purse seine (Photo: Bruno Barracuda)

4.2 Loading and unloading the catch

The fish are pumped from the fishing gear onto the vessel. When fish are pumped up from the purse seine, the majority of the fish are usually alive during the first few minutes of the pumping. As time passes during loading, an increasing proportion of dead fish in the purse seine is registered. How non-damaging the pumping process is depends on the type of pumping, the catch volume and the level of crowding. Pumping capacity, pressure and speed, lifting height, the diameter of the pump and the pumping hoses, and the angle of the bend that the fish pass through can all influence how much damage the fish sustain. It is not uncommon to see various types of blood damage (extravasation into the muscles to a greater or lesser extent), knocks and crushing injuries from the loading and unloading of the catch (Heia et al., 2013; Roth et al., 2013). Fish that survive capture and pumping die when they enter the chilling tank. On delivery, the fish are pumped out of the boat and into the fish landing centre (Aursand et al., 2012; Tveit et al., 2017). It is not known whether pumping has an effect on the salt content of the fish, other than as a result of the stress of the process on live fish. In the case of more serious injuries to the fish during loading and unloading, there may be places where seawater can more easily penetrate the fish during the subsequent chilling in seawater.

4.3 Chilling

It is essential to chill the catch quickly after the fish have been brought on board the vessel, in order to ensure the best possible quality and durability until processing (Burt et al., 1992; Mallikage, 2001; Nielsen & Hyldig, 2004). Fish for human consumption must be cooled to below 3 °C within 6 hours of capture, and then to below 0 °C within 16 hours (Norges sildesalgslag, 2022). Catches often weigh as much as 50–100 tonnes, and it is not uncommon for the temperature to be around 8–10 °C when the catch is brought onboard. A great deal of energy is required to cool such large volumes down to around 0 °C. To deal with this situation, the Norwegian herring fisheries typically use RSW (Refrigerated Sea

Water). The salt in the seawater makes it possible to cool the water down to below 0 °C, which is a good starting point when the aim is to reduce the temperature in the catch as quickly as possible.

Some vessels use CSW (Chilled Sea Water) which is seawater mixed with ice, or RFW (Refrigerated Fresh Water) which is chilled fresh water, for individual catches of herring, and for the refrigerated storage of other pelagic species. On account of osmosis, fish stored in fresh water will assimilate some water, leading them to have a lower salt content, whereas fish stored in seawater will have a higher salt content. **The time spent** in the tank will affect how much salt the fish assimilate from the seawater (Figure 2). The salt content in CSW will be a little lower than when pure RSW is used, but fish stored in CSW will still assimilate some salt (Aursand et al., 2012; Mallikage, 2001; Widell & Nordtvedt, 2016).

The fill level of fish in relation to the sea water in the tanks will affect how much salt is available for each individual fish to assimilate, and this will naturally affect salt assimilation and the amount of salt in the fish when the catch is unloaded. It is common to work with fill levels of around 60% fish and 40% water if the fish are destined for human consumption. If the catch is intended for processing into fish meal and oil, it is more common to fill the tanks with 70–90% fish. Lower fill levels allow good circulation of water around the fish, good cooling and, as a result, better quality. Lower fill levels also make more salt available, such that fish intended for human consumption will likely achieve a higher salt concentration than fish destined for processing into fish meal and oil if they both spend the same amount of time in RSW (Widell & Nordtvedt, 2016).

The salinity of RSW is not standardised, but unless extra salt is added to the water, the salinity will be the same as in the sea from which the seawater was extracted. In the Bay of Bothnia or the Baltic Sea, for example, the salinity will be lower than in the North Sea or the Norwegian Sea. The salinity in the Bay of Bothnia is less than 0.5%, while in open waters it is around 3.5%. Results of various tests have shown that the salt content of Baltic herring was lower than that of Atlantic herring (Breen, 2003; Hattula et al., 2002; Tahvonen et al., 2000).

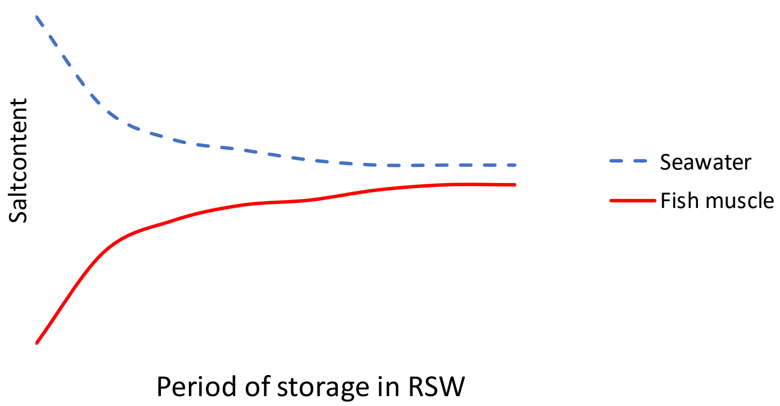

Figure 2 This figure shows a theoretical representation of changes to salt content in fish muscle and seawater during storage in RSW. The salt content of the seawater and the fish muscle will gradually equalise during the period of storage.

4.3.1 Salt assimilation during storage in RSW

How quickly fish assimilate salt and obtain content levels equal to their surroundings depends on the storage time in RSW and the size of the fish. This equalization process takes less time in small fish than in larger fish. In addition, salt assimilation is quickest at the start, when the difference between the salt content of the fish and the water is greatest (Perigreen et al., 1975). Salt assimilation is measurable after just a few hours in RSW. Salt assimilation during storage is not evenly distributed in all parts of the fish. The part of the fish that is closest to the seawater showed significantly higher concentrations of sodium than the inner parts of the fish. The difference in concentration between the different parts of the fish is measurable after just a few hours in RSW, and this difference increases during the storage process (MacLeod et al., 1960).

4.3.2 Chilling in relation to alternative commercial use of the catch

How the fish are chilled will vary depending on the intended commercial use of the catch. If the fish are intended for human consumption, they are subject to completely different quality requirements than those that apply to fish used for meal/oil. The temperature of fish for human consumption is checked from capture to delivery. It is essential that there be sufficient chilling on board to ensure that the catch is fit for human consumption. All fish that are destined for human consumption are initially chilled on board the vessels – this also applies to fish that are to be processed, packed and frozen for remarketing. For this reason, it is to be expected that the salt content of frozen herring is the same as that of fresh herring (Norges sildesalgslag, 2022).

Industrial fish intended for the production of meal and oil are checked for their content of salt and Total Volatile Basic Nitrogen (TVB-N), because threshold limit values apply to these contents. The threshold limit values are 0.75% NaCl/100 g fish and 31 mg TVB-N/100 g fish, and exceeding these values results in a reduction of the price of the catch. Tangible measures are therefore applied to guard against exceeding the threshold limit values, in order to keep the price of the catch as high as possible (Norges sildesalgslag, 2023).

It is expensive to keep an RSW installation running, and the lower the temperature required for the catch, the more energy is required. In the case of industrial fish, savings can be made by not keeping the temperature of the catch as low as is necessary for fish for human consumption. Fresh water is often added to the RSW to keep the salt content of the catch below the threshold limit value. As mentioned previously, it is also common to work with higher fill levels when the tanks are filled with industrial fish, and this also results in there being less salt available for the fish to assimilate. The salt in RSW leads to slower bacterial growth compared to storage in RFW. Both the higher storage temperature and the reduced salinity during chilling can cause faster bacterial growth. Total Volatile Basic Nitrogen (TVB-N) is formed during the bacterial decomposition of nitrogen-containing extractive substances and protein in fish muscle. This means that for each day of storage – or if the chilling is insufficient – more TVB-N will develop in the herring, and the value of the catch will decrease. Bacterial growth can be inhibited during the storage of industrial fish by adding vinegar to the chilling medium (Malle & Poumeyrol, 1989; Mallikage, 2001; Widell & Nordtvedt, 2016). This cannot be done in the case of fish for human consumption.

5 How sampling affects the results

The results of sampling and salt determination will be affected by the methods used. In the literature examined, differences were identified in the salt content in fish depending on what part of the fish was processed for the sample, and which analysis method was utilised.

As regards preparing the sample material prior to analysis, the greatest difference in the material examined was that some operators grind up the entire fish for analysis, while others use only the muscle (the fillet) of the fish for analysis. This affects the results because there are much higher concentrations of salt in the head, the gills, the stomach and the intestines than in the fillet itself. (Wu *et al.*, 2022). Egerton *et al*. (2020) examined the salt content in three species of fish, of which herring was one. They immediately froze the fish to -20 °C on board the vessel. In their examination, the entire fish was homogenised before the salt content was analysed. They measured 218 mg Na^+/100 g fish. When the Institute of Marine Research (IMR) conducted analyses of the salt content in the muscle (fillet) of herring in 2020 (NIFES, 2023), they measured an average of 103 mg Na^+/100 g fillet. IMR used ICP-MS analysis – a spectrometric method – to measure the sodium content of the fillet. This demonstrates that there significant differences can arise, depending on whether salt content is measured in the entire fish or whether only select parts of the fish are analysed.

5.1 Sampling and methods for determining salt content in herring utilised in Norway and in Brazil

There are several organisations that develop analysis methods. Biolab (Nofima, Bergen), which analyses samples in Norway, and the authorities in Brazil both use methods developed by the "Association of Analytical Communities (AOAC)". This organisation is an independent developer of analysis methods, and the methods currently used can be found on www.AOAC.org.

In Brazil, the *Ministério da Agricultura, Pecuária e Abastecimento* (Ministry for Agriculture, Livestock and Supply) has decided what is to be sampled and which methods are to be applied. These are described in the *Métodos Oficiais para Análise de Produtos de Origem Animal* (Official methods for the analysis of products of animal origin). Section 5 describes the sampling of fish and fish products, and subsection 5.24 stipulates the method to be used for analysing the sodium content in fish. They prepare the samples in accordance with AOAC 937,07, where the fish are cleaned to remove certain parts before the samples are excised. The selected samples from the fish are ground up before the sodium content of the muscle is determined in line with the method described in AOAC 969,23.

It was not possible to access historical results of analyses performed on Norwegian herring in Brazil in order to establish a broader picture of what salt content is measured in fish in that country, but we did obtain the analysis results from a single, specific case. Measurements of frozen natural herring exported from Norway revealed a content of 169 mg sodium/100 g fillet. The importer therefore requested a new analysis of the same sample, and the new sample result was 213 mg/100 g fillet.

In Norway the practice is to comply with Circular 14/14: Guidelines for checking ingredients and instructions for sampling. These guidelines describe what is to be sampled and how the material for the sample is to be extracted. Only pelagic fish intended for the production of meal and oil are to be checked in accordance with these guidelines. Biolab analyses samples by following method AOAC 937,09, where the samples are analysed for sodium chloride (NaCl), also known as common salt. In Norway, Biolab receives a ground up fish mass consisting of entire fish – i.e. including the head, intestines, skin, bones and fins. At present, no routine check is performed of salt levels in natural herring intended for human consumption.

5.2 Analyses of ingredients used for meal and oil

As such, two different methods are used for analyses. The sampling method used on industrial fish in Norway can result in slightly higher values of salt content than the method used on samples of fish for human consumption in Brazil. In addition, differences in the catch handling and chilling of fish for human consumption may result in these fish containing more salt than fish from industrial fishing. We have examined analyses performed on industrial fish. Even though the results are not directly comparable, they nevertheless provide a good indication of the levels of salt to be expected in fish for human consumption.

Biolab analysed the salt content in 868 catches of NSS-herring and North Sea herring from the period January 2018 through January 2023 (Based on data from the Norwegian Fishermen's Sales Organization for Pelagic Fish (*Sildesalgslaget*) and Biolab). Of these, 751 catches were chilled using RSW and 82 were chilled with RFW. Catches chilled using other methods (35) were not included. The results are shown in Figure 3, which presents the quantity landed, divided by salt content in the fish. The black line indicates the threshold limit value set in Brazil, and only the catches to the left of this line would be within the threshold limit. The vast majority of the catches would therefore be rejected, and the salt content would be too high even in the majority of the catches reported as chilled in fresh water.

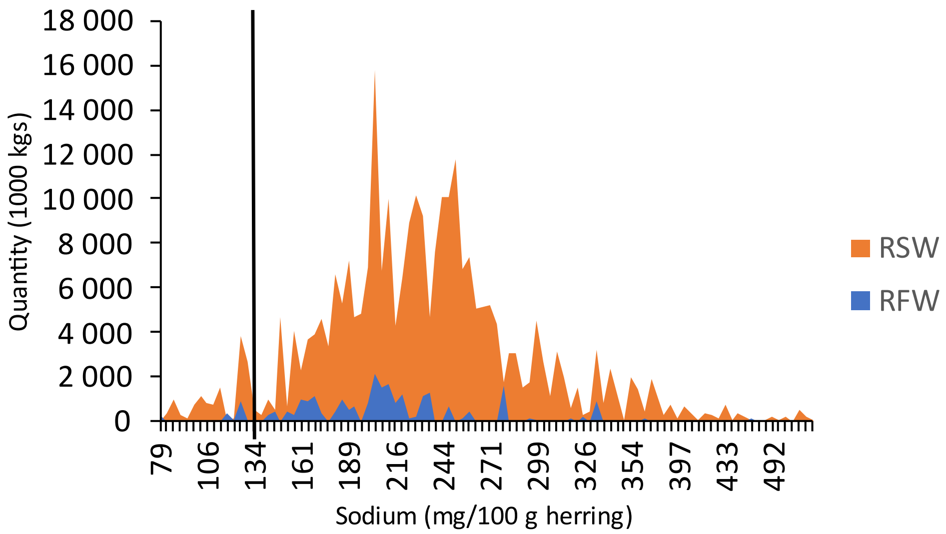

Figure 3 Quantity of industrial herring chilled in RSW (orange) and RFW (blue) landed in the period 2018 through 2023, divided by the sodium content in the catch. Brazil's threshold limit value of 134 mg/100 g fillet is marked with a black line.

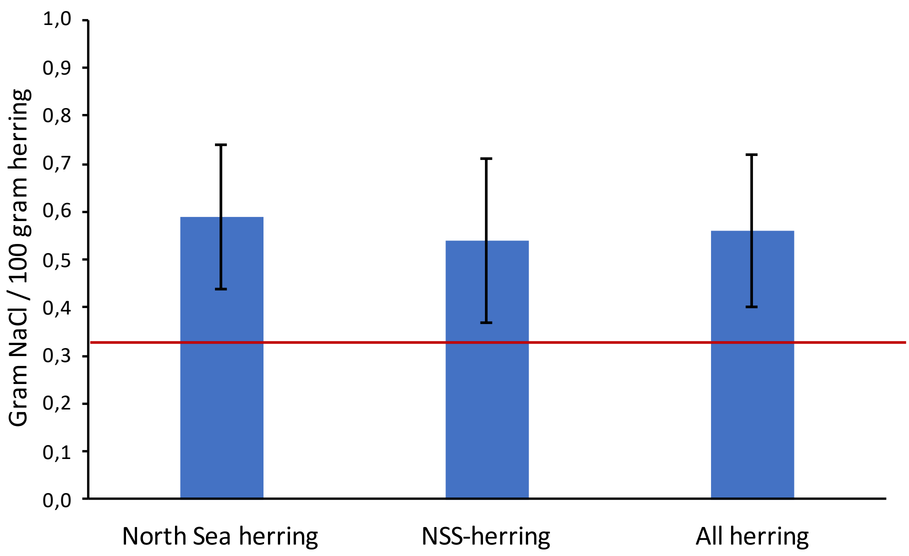

Figure 4 Average salt content (g NaCl per 100 g fish) in herring delivered for the production of fish meal and oil in 2022. The threshold limit value for salt content in Brazil is marked with a red line.

In 2022, a total of 225 analyses were performed on NSS-herring and 133 on North Sea herring, making a total of 358 analyses (Based on data from the Norwegian Fishermen's Sales Organization for Pelagic Fish (*Sildesalgslaget*) and Biolab). The results of these analyses are presented in Figure 4. The red line in the figure indicates Brazil's threshold limit value of 0.134 g sodium (Na^{+}) converted into amount of NaCl per 100 g fish: 0.335 g. As the figure shows, the average value for all herring – both North Sea herring and NSS-herring – is clearly above the threshold limit value set by Brazil. The lowest measured values were only slightly below the threshold limit value (0.25% for North Sea herring and 0.2% for NSS-herring), while the average values were 0.59% and 0.54%, and the highest values 1.16% and 1.1% for the respective species).

Figure 5 shows how the salt content in the samples from 2022 changes as a consequence of the time spent stored in RSW. As the figure demonstrates, the salt content in the fish increases in line with the time spent in RSW chilling. As early as on Day 0, there is a significant spread in the salt content, and if the Brazilian threshold limit value is used as the base, several catches featured a salt content that was already too high at the time the catch was made. Here, it is relevant to note that even though the salt content of the fish increases in step with the time in storage, there is still a significant spread in how much salt the fish contain. This may be due to the fact that when the fish are destined for processing into fish meal and oil, fresh water is sometimes added to the RSW in order to reduce the amount of salt in the water – and thus in the catch. In addition, there may be large variations in the fill level (70–90% fish) in the RSW tanks between the different catches, a factor that also affects the amount of salt in the fish.

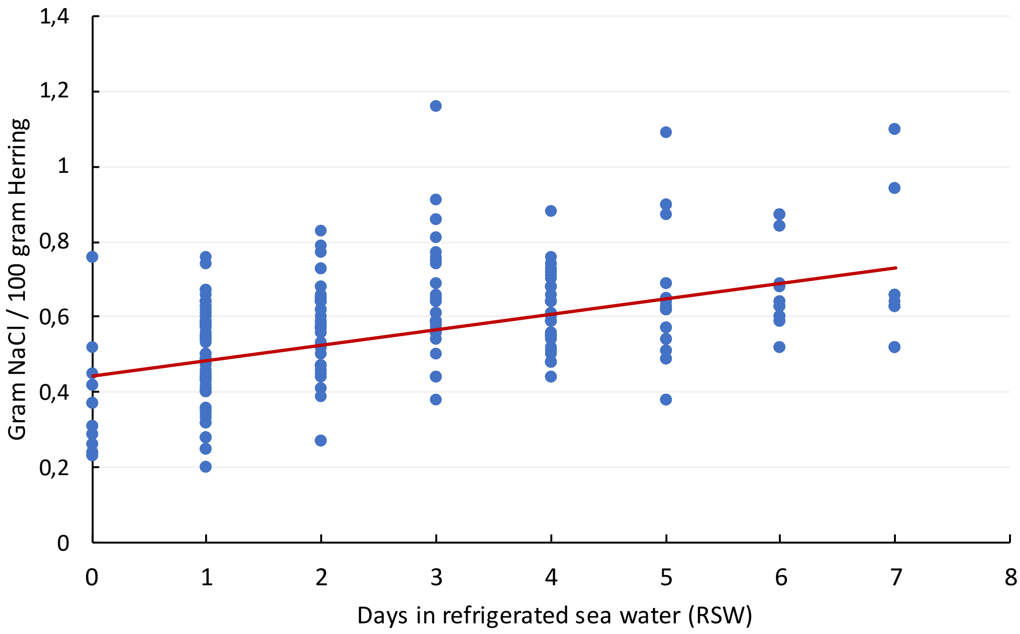

Figure 5 Measured changes in salt content (NaCl) in herring during storage in RSW. The figure is based on data from the Norwegian Fishermen's Sales Organization for Pelagic Fish (Sildesalgslaget) *and Biolab.*

A PLS (Partial Least Square) regression analysis was performed in order to examine what has the greatest effect on salt content in herring (dataset from 2022) between RSW, temperature of catch on unloading, fat percentage, fat-free dry matter, TVB-N and size of catch. The results are presented in Figure 6. The variables that are of significance to the salt content in herring are marked with a black ring around the blue dots in the figure. The number of days in RSW and the size (quantity) of the catch are the factors of greatest significance to the salt content. Salt content and temperature of the catch on unloading correlate inversely. This means that when the temperature on delivery is high, a low salt content is expected. The reason for this is probably short or entirely lacking storage in RSW, given that the herring delivered at a high temperature were typically delivered on the catch day itself or the day after. TVB-N also correlates to salt content, but not as strongly as days in RSW and quantity. A higher content of TVB-N is accompanied by a higher salt content.

As regards fat percentage, this also correlates with the salt percentage, but not to as great a degree as days in RSW, quantity and temperature. A part of the reason for the lower correlation may be the relatively small variation in the data material as regards quantity of fat in herring, and between the different catches.

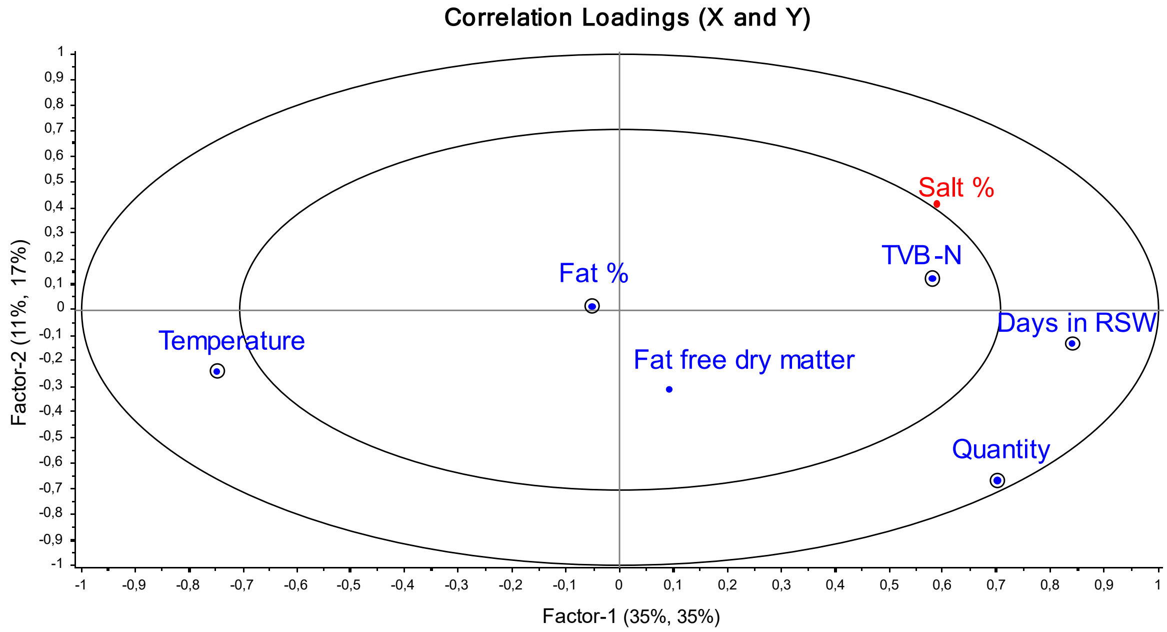

Figure 6 Correlation Loadings (X and Y) where the X-variables (written in blue) are examined for correlation with Y – salt content (written in red) – in herring destined for production of fish meal and oil. The points of significant variables are circled in the figure.

6 Discussion

Different quality requirements apply to fish intended for production of fish meal and oil than to fish destined for human consumption. This affects the catch handling on board, and thus the salt content in the fish.

Chilling fish in RSW is a necessary step in the process to preserve the quality of pelagic fish. This makes it possible to transport large volumes of fish from the point of capture to reception facilities in an efficient and less harmful manner, such that the inherent quality of the fish is not appreciably affected. This is essential in ensuring that the quality of the fish remains sufficient for human consumption. Norwegian fishing for herring is often carried out a good distance from land, which means that catches can be stored in RSW for several days prior to delivery. This, in turn, means that salt assimilation in the fish is unavoidable. Herring destined for human consumption are not analysed for salt content, so it is not known how much salt these fish contain.

Stress causes an increase in salt ions in the herrings' blood, and the level can continue to rise for several days after the cause of the stress has ceased (Tenningen et al., 2012). It is unclear whether the salt content in fish that have been subjected to stress will exceed the values that Murray & Burt (1969) or Sidwell *et al.* (1977) stated as normal variations. Research into physiology and fish welfare has focused on the level of salt ions in fish blood, rather than salt content in the entire fish. Herring and other pelagic fish of relatively small size are not bled, which means that the blood remains a part of the entire fish. There are no figures to show how great an effect this actually has on the total salt content in the fish.

This report has taken herring as its basis, but the different factors that affect salt content of fish also apply to other species of fish. Natural regulation of salt (osmosis regulation) and catch handling that includes RSW, time in RSW and temperature will all affect the salt content of fish. There may be differences in how great an influence different species can tolerate before it has an effect on salt ions in their blood during capture, and there may also be differences in how long fish take to recover after such an influence. What is of greatest significance to the salt content is the size of the fish and the time spent in RSW, which affects how much salt the fish assimilate. It takes longer for larger fish such as salmon, cod and pollock to achieve equilibrium with their surroundings than it takes for smaller fish such as coalfish, anchovy, mackerel, herring and European sprat (Chan et al., 2021; Chan et al., 2020; Chaouqy et al., 2008; Joensen et al., 2000; Losnegard, 1992; Nordtvedt & Widell, 2019).

Brazil introduced the threshold limit value of 134 mg sodium/100 g fillet in 2017 through the implementation of a set of regulations applicable to frozen products. When the threshold value is set as low as the levels encountered naturally in live fish, it seems that Brazil is not aware that in Norwegian pelagic fishing, the catches are only chilled on board the vessels and that freezing does not take place until after landing. Frozen natural herring exported from Norway must therefore be expected to have a higher salt content than the stated threshold limit value of 134 mg sodium/100 g fillet. In order to achieve sodium values lower than 134 mg/100 g herring fillet, an option could be to freeze the fish on board, immediately after capture, without first chilling them in RSW.

7 Conclusion

Stress, capture and catch handling affect the salt content in fish, but the factor that has the greatest impact on salt content is chilling the catch in water that contains salt. The method most commonly used to chill pelagic fish is RSW (Refrigerated Sea Water). How much salt fish assimilate during storage will vary depending on the concentration of salt in the water, how much water is in the tank in relation to the volume of fish, the size of the fish and the length of time the fish are stored in RSW.

A broader study should be carried out on RSW chilling of fish and how this affects the development of the volume of salt in herring, other pelagic fish, white fish and salmonids destined for human consumption.

Given how commercial fishery and the transport of herring in RSW to reception facilities are conducted today, the threshold limit values for salt content in frozen herring exported to Brazil are unrealistic. It will not be possible to export the majority of the herring fished and landed in Norway to Brazil for human consumption, because the salt levels in the fish muscle from the majority of catches will exceed the stated threshold limit value of 134 mg sodium/100 g herring fillet.

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