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WORLD SEAFOOD CONGRESS 2023
PENICHE, PORTUGAL 25-27 SEPTEMBER

Supercooling for Seafood

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National Centre for Food Manufacturing (NCFM) - Grimsby Site

University of Lincoln, UK

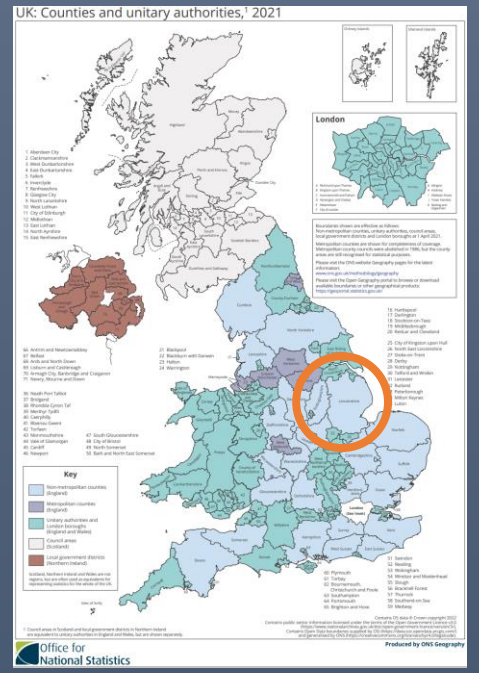
UK SEAFOOD INNOVATION FUND

Content

1. University of Lincoln & Agri-Food
2. Seafood Supercooling Feasibility Study (May 2022 → Sep 2022)
3. Follow On Project (May 2023 → Oct 2024)

Greater Lincolnshire, UK

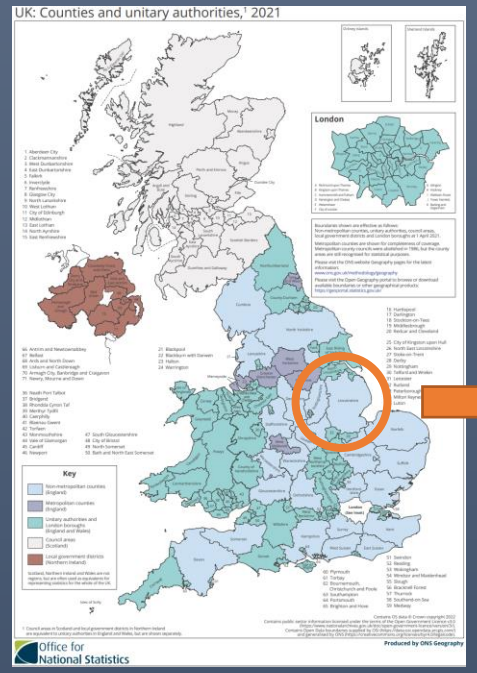
- East Midlands region of the UK
- Agri – Food sector is of vital importance in the region
- 75,000 food sector jobs
  - (18% of employment, national average 4%)
- Region contains leading UK clusters in seafood processing, vegetables, salads and fruit, poultry, meat, eggs and arable crops
- 15% of all UK Agricultural produce grown
- 70% of all UK seafood processed

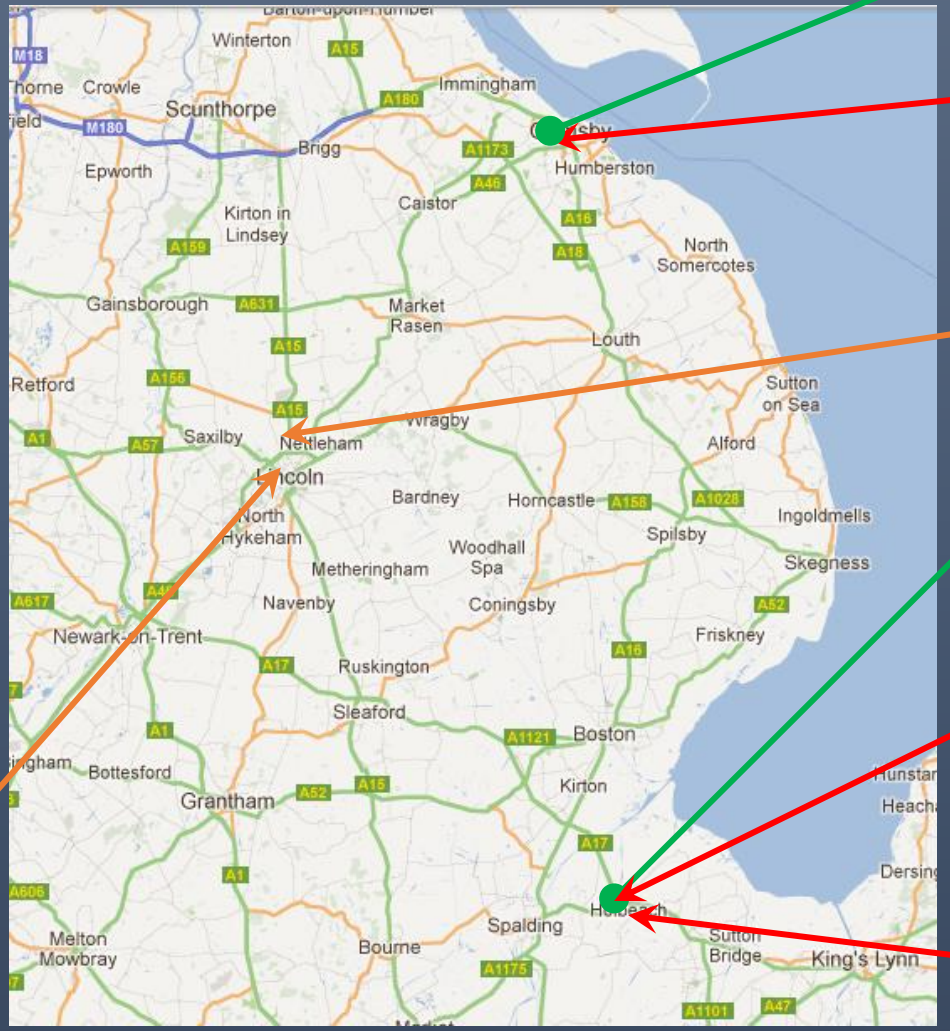


Greater Lincolnshire
Local Enterprise Partnership

- University of Lincoln:
- Knowledge Transfer and Academic support to underpin & support the sector

UK FOOD VALLEY





NE Lincs Food Enterprise Zone (FEZ)

NCFM-Grimsby

Riseholme Park & LIAT

S Lincs Food Enterprise Zone (FEZ)

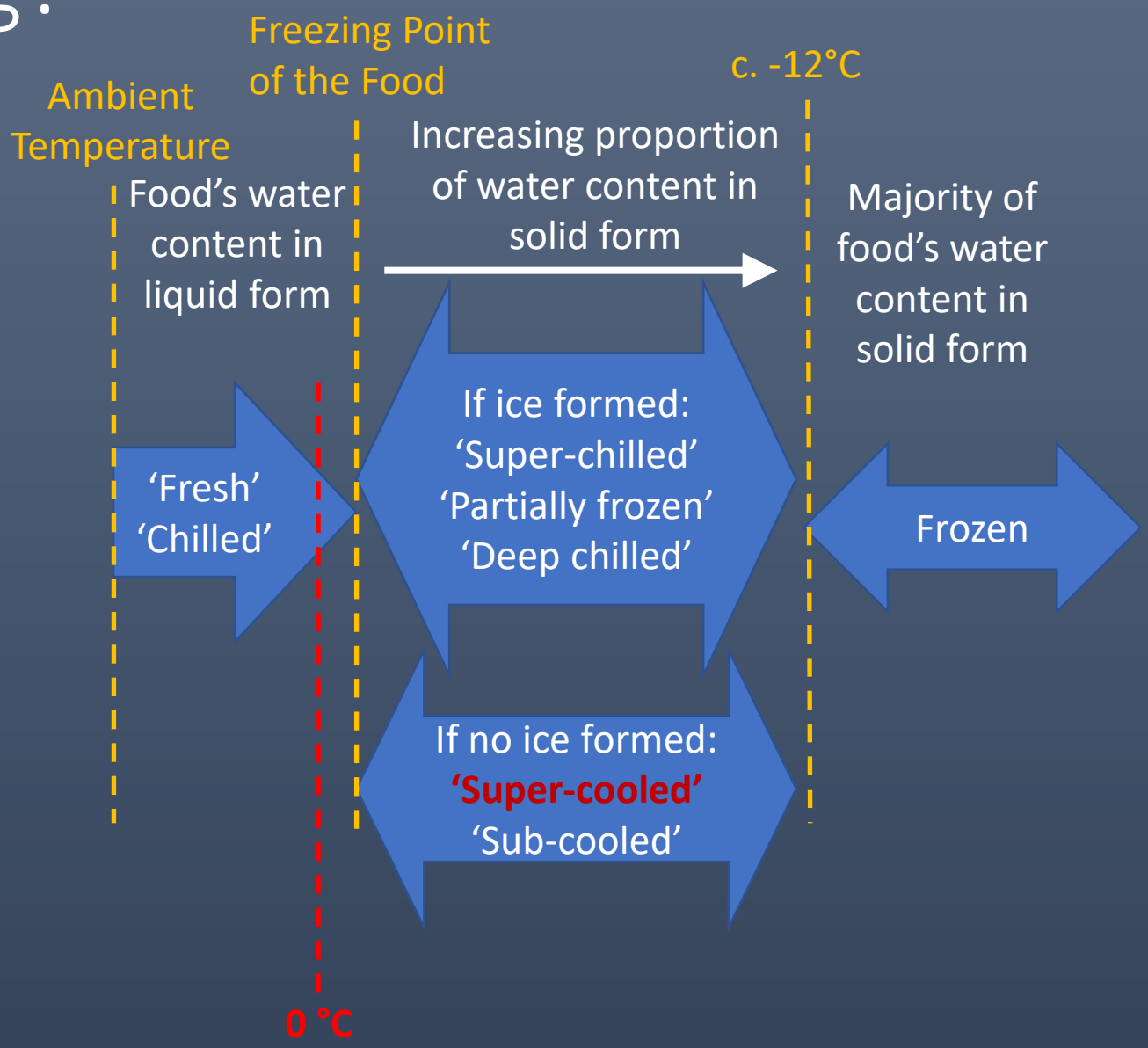
NCFM-CoE

NCFM-Factory

University of Lincoln Main Campus Brayford Pool

What is Super-cooling?

- A physical phenomenon where products containing water can be cooled to below their freezing point (typically 1-2 degrees lower) without nucleation of ice crystals
- Super-cooling potentially offers an extended shelf-life while avoiding detrimental ice crystal formation and maintaining fresh textural integrity



Feasibility Project Premise

- Fresh seafood is highly perishable
- Historically UK seafood is kept, “at the temperature of melting ice”, i.e., 0°C
- However, the lower the temperature the longer the shelf-life.
  - Seafood that keeps for 14 days in ice (0°C) will theoretically keep 17, 22, and 29 days at -1°C, -2°C and -3°C, respectively *(Huss, 1995)*
- Freezing and partial freezing (super-chilling) extends shelf-life, but ice formation affects quality and value, thus makes the product less desirable
- Freezing point generally believed to limit the lowest temperature at which chilled seafood can be stored
- Super-cooling is a potential alternative to extend the high-quality shelf-life of chilled seafood by lowering the temperature below the freezing point without ice forming
  - Potential to improve process flexibility, while reducing energy and waste
  - A few days extension to shelf-life could substantially improve the cost effectiveness of seafood production

Feasibility Project Activity

- Build supercooling test rigs
- Establish parameters for reliable super-cooling
  - Range of species, all vacuum-packed
  - Determine initial freezing point temperatures
  - Select four exemplar species
- Quantify stability of super-cooling
  - Quantify how long vacuum-packed exemplar species could be kept in super-cooled state
- Compare quality of super-cooled product with conventional chilled storage
  - Two exemplar species
  - Organoleptic tests

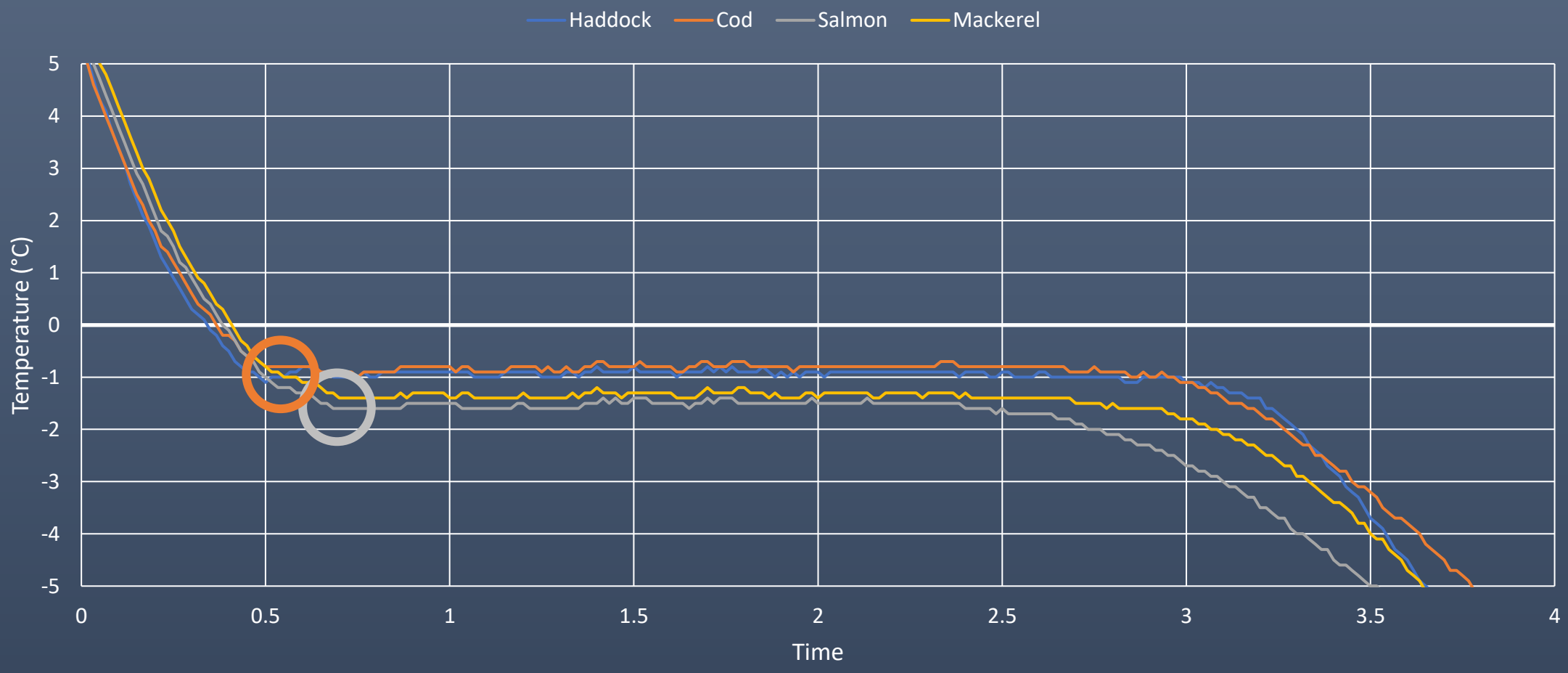
Equipment

- Several different designs of chambers were used for the project
- Modified chest freezers
  - Fixed offset heaters adjusted between runs to give conditions just below desired run temperature
  - Smaller heaters under separate control to fine tune temperatures

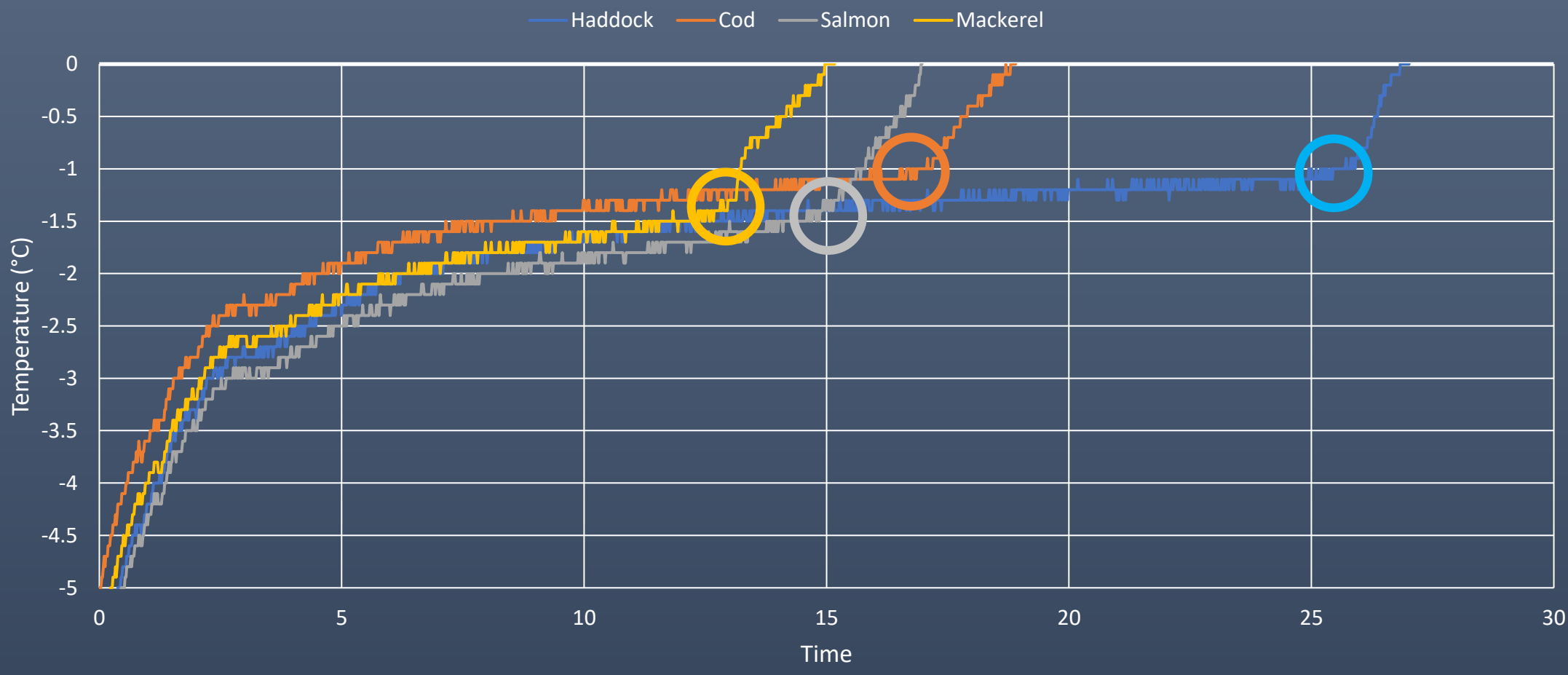
Susceptibility to Supercooling (& Freezing Points)

- Range of species instrumented and subjected to storage at a range of temperatures
- Where temperature plots showed freezing, freezing point was determined by/from:
  - Freezing plateau from freezing curves measured in samples frozen under standard conditions
  - Thawing plateau from thawing (defrosting) curves measured in samples thawed (defrosted) under standard conditions
  - Temperature immediately after a nucleation event in temperature histories measured during super-cooled storage
- Where temperature plots did not show freezing – possibility of supercooling

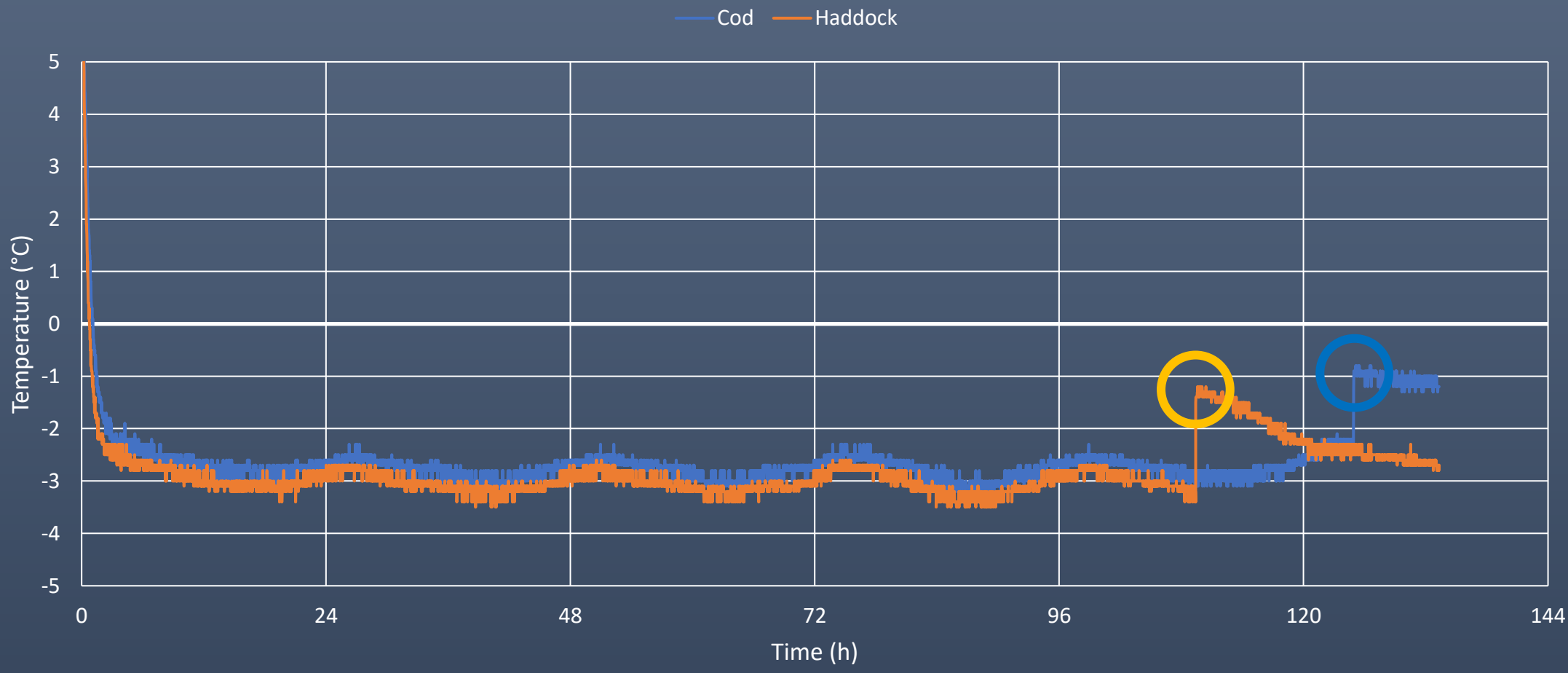
Freezing Point Determined from Freezing Curve



Freezing Point Determined from Thawing Curve



Freezing Point Determined by Nucleation from temperature history during super-cooled storage



Freezing Points

Species	Freezing curve	Thawing curve	Nucleation during super-cooled storage	Overall mean
Bream	n/a	n/a	-0.7 (0.38), -0.4, -1.1	-0.7
Cod	-1.1 (0.29), -0.7, -1.6	-1.0 (0.10), -0.9, -1.1	-1.1 (0.41), -0.6, -1.6	-1.1
Haddock	-1.1 (0.23), -0.7, -1.3	-1.1 (0.06), -1.0, -1.1	-1.4 (0.33), -0.9, -1.8	-1.2
Mackerel	-1.4 (0.33), -0.9, -1.9	-1.2 (0.25), -1.0, -1.5	-1.5 (0.41), -0.8, -1.9	-1.4
Plaice	-1.1 (0.14), -0.9, -1.1	n/a	-0.4 (n/a), -0.4, -0.4	-0.8
Salmon	-1.4 (0.31), -1.1, -1.9	-1.3 (0.25), -1.1, -1.6	-1.7 (0.17), -1.5, -1.8	-1.5
Sardine	n/a	n/a	-1.0 (n/a), -1.0, -1.0	-1.0
Sea Bass	-2.2 (0.72), -1.2, -3.2	n/a	-1.0 (0.14), -0.9, -1.3	-1.5

Format: mean (SD), max, min

Prawn, Scallop, Sole, & Skate did not exhibit freezing during super-cooling trials, separate freezing and thawing trials were not carried out on samples of these species

Lowest temperatures observed without signs of nucleation (freezing)

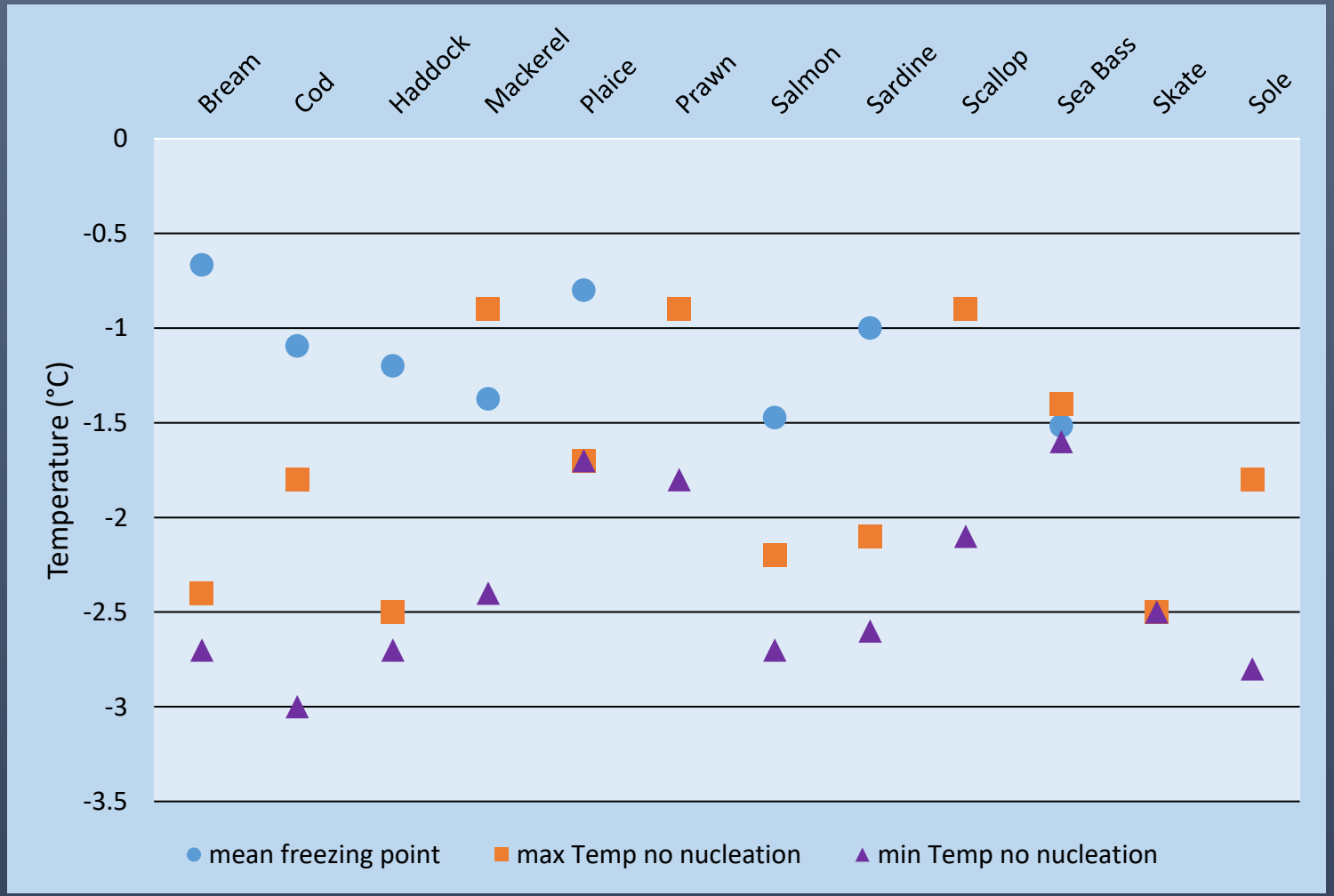
- Some trials showed no signs of nucleation (freezing), indicating that:
  - The freezing point of the sample was lower than the storage temperature

  Or
  - The fish had super-cooled
- Lowest temperatures observed without signs of nucleation

	Bream	Cod	Haddock	Mackerel	Plaice	Prawn	Salmon	Sardine	Scallop	Sea Bass	Skate	Sole
Mean	-2.5	-2.5	-2.6	-1.6	-1.7	-1.4	-2.5	-2.4	-1.5	-1.4	-2.5	-2.4
SD	0.12	0.33	0.10	0.46	n/a	0.37	0.2	0.26	0.42	0.09	0.00	0.36
max	-2.4	-1.8	-2.5	-0.9	-1.7	-0.9	-2.2	-2.1	-0.9	-1.4	-2.5	-1.8
min	-2.7	-3.0	-2.7	-2.4	-1.7	-1.8	-2.7	-2.6	-2.1	-1.6	-2.5	-2.8

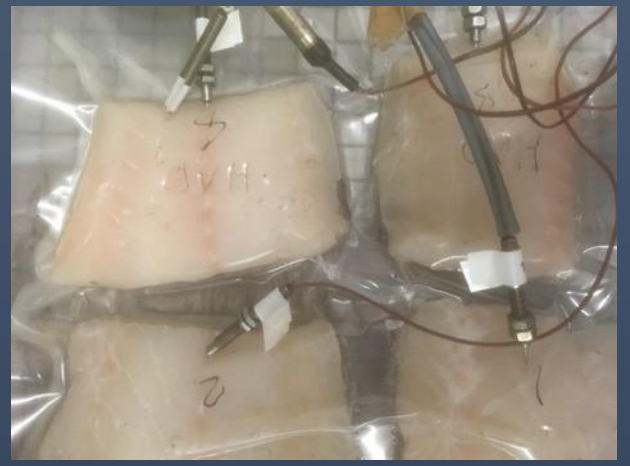
Freezing points & No-Nucleation (super-cooled) Temperatures

- Freezing points warmer than ‘No Nucleation’ shows species propensity to super-cool
- With exception of sea bass and skate, all showed some propensity to super-cool
- Cod, Haddock, Mackerel, Salmon chosen for more detailed studies into stability of super-cooling
- Target super-cooled temperature -2°C chosen as most stable



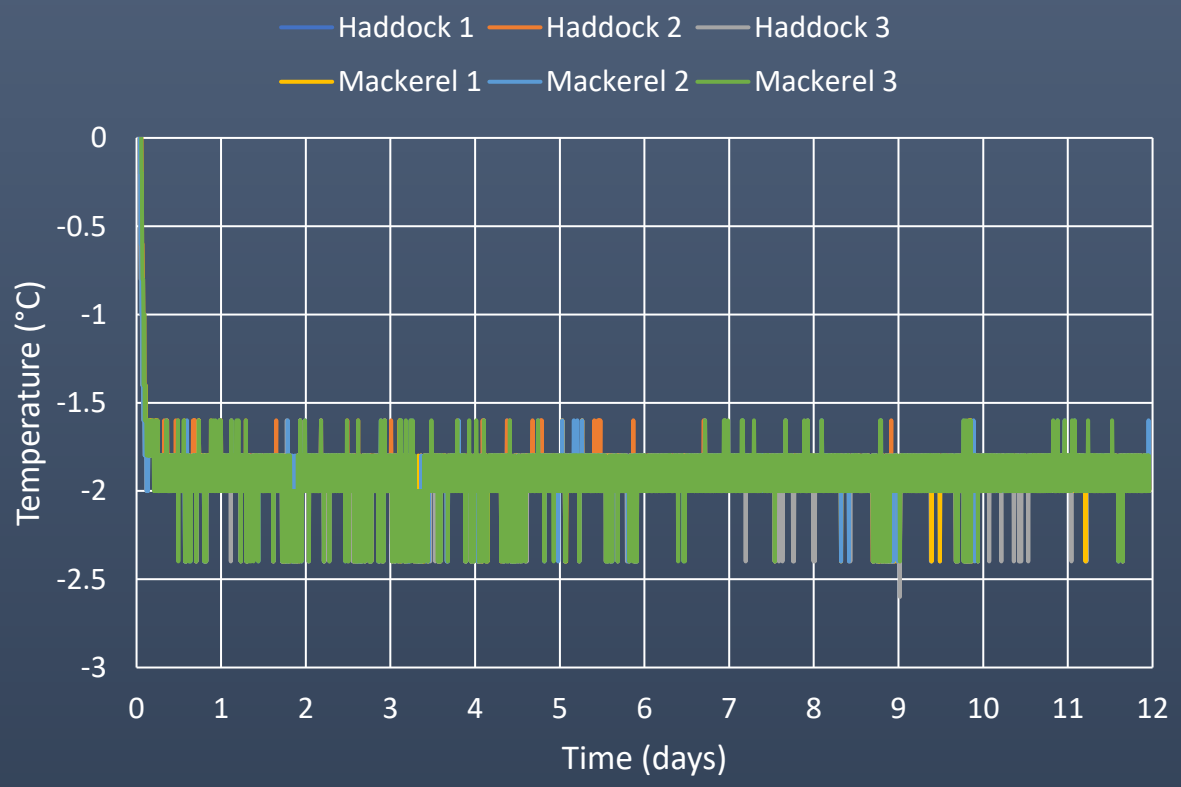
Stability of Super-cooled Storage

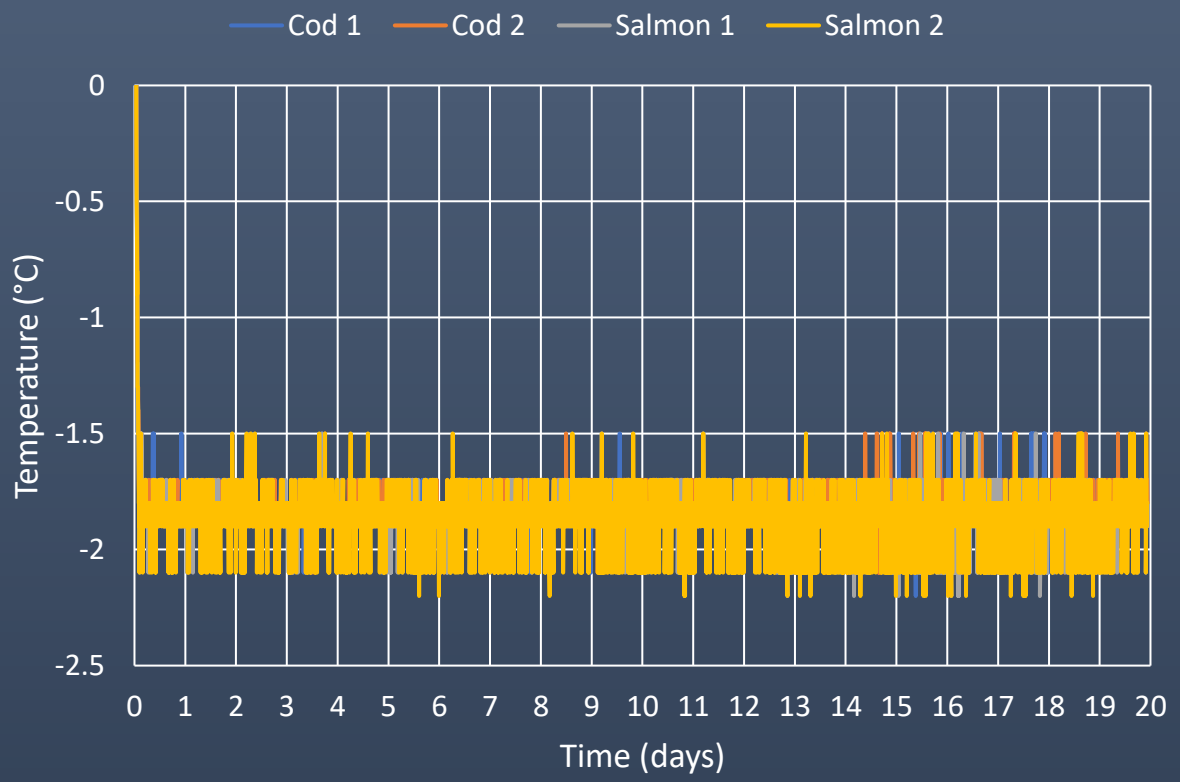
- Stability (i.e. no nucleation) is a vital element for super-cooled storage to be useful in industrial practice
- Exemplar species, Cod, Mackerel, Haddock, and Salmon were held in a stable super-cooled state (-2°C ± 0.5 °C)
- No species showed nucleation during the experiential durations
- Retail packed Mackerel & Haddock showed stable super-cooling for at least 13 days (trial terminated after 13 days)
- Retail packed Cod & Salmon showed stable super-cooling for at least 20 days (trial terminated after 20 days)



Stable Super-cooling in retail-packed Haddock, Mackerel, Cod, and Salmon

- All Samples remained soft to the touch and unfrozen throughout these trials
- No rapid temperature rises to the freezing point were observed in the measured temperature history indicating no ice nucleation occurred during storage





Initial Shelf Life Assessments

- Vacuum packed Cod & Salmon direct from processor's line
- 3 storage conditions (all c. ±0.5 °C)
  - Control: (+5°C) to replicate retail display/consumer storage
  - Partial supercooled: 2 days supercooled (-2°C) followed by (+5°C) to represent a supercooled early part of chain
  - Full supercooled: (-2°C) to represent a longer supercooled chain
- Assessed
  - Pack opening odour
  - Cooked taste

Organoleptic assessment – Odour on pack opening

- 5-point scale* based upon the Torry organoleptic scales
  *[5 fresh, 4 aging but OK, 3 threshold, 2 slightly spoiled, 1 unpalatable]
- 3 independent assessors, amalgamated results

Cod (days after end of normal pack life)

Storage conditions	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Control	2	2.5	1	1	1	1	1
Partially Super-cooled	4	4	2.5	2.5	2	2	1.5
Fully Super-cooled	5	5	4.5	4.5	4	3.5	3.5

Salmon (days after end of normal pack life)

Storage conditions	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Control	3.5	3	3	2	2	1.5	1
Partially Super-cooled	4	5	5	4	3	4	2
Fully Super-cooled	5	5	5	5	4	4	3.5

Organoleptic assessment – Cooked Taste

- 5-point scale* based upon the Torry organoleptic scales
  *[5 fresh, 4 aging but OK, 3 threshold, 2 slightly spoiled, 1 unpalatable]
- 3 independent assessors, amalgamated results

Cod (days after end of normal pack life)

Storage conditions	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Control	1.83	1.67	1.33	1.00	1.00	1.00	1.00
Partially Super-cooled	3.67	3.50	2.00	1.83	1.33	1.17	1.00
Fully Super-cooled	4.33	4.67	4.00	3.67	3.67	3.33	3.17

Salmon (days after end of normal pack life)

Storage conditions	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Control	3.83	3.67	3.67	3.00	3.17	2.83	2.50
Partially Super-cooled	4.50	4.83	4.50	3.50	3.83	4.17	3.83
Fully Super-cooled	4.83	4.83	5.00	4.50	4.83	4.50	4.17

Practical Shelf-Life (PSL)

- Duration post pack until unacceptability threshold

Cod	Pack Open Odour	Post Cook Taste
Control	<8d	<8d
Part super-cooled	10d	10d
Super-cooled	15d	15d

Salmon	Pack Open Odour	Post Cook Taste
Control	11d	13d
Part super-cooled	12d	15d
Super-cooled	15d	15d

- Extension to current shelf-life

with respect to control sample	Cod	Salmon
Part super-cooled	>2d	1d
Super-cooled	>5d	4d

with respect to pack stated life	Cod	Salmon
Part super-cooled	2d	4d
Super-cooled	5d	7d

Feasibility Conclusions

- Many seafood species exhibited super-cooling behaviour
- Stable super-cooled storage at -2°C for up to 20 days was demonstrated in retail packed exemplar species
- Shelf-life extensions up to 7 days longer than current norms were observed
- Even a short period of super-cooled storage was observed to extend shelf-life by 2 days

- Feasibility study results were encouraging

Objectives of the follow up project

- Clarify factors that affect stability of super-cooling
  - Packaging, Species, Temperatures, Fluctuations, Cooling rates
- Clarify the impact of super-cooled storage on the microbiota profile and spoilage characteristics, and product quality
- Identify suitable deployment location for supercooling along the Seafood Supply Chain
- Examine the commercial cost-benefits of implementation
- Demonstrate at a scale relevant to industrial adoption

Current progress in follow up project

- Rigs constructed and being commissioned
- Industrial Stakeholder Group established
- Initial industrial discussions completed on potential areas for application for super-cooling
  - Harvest to processor – allowing fish from more distant suppliers
  - WIP in processor – allowing more process flexibility
  - At food service outlet – less waste + higher quality eating experience
  - At retailer – less waste

Thank You For Listening - Any Questions?

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