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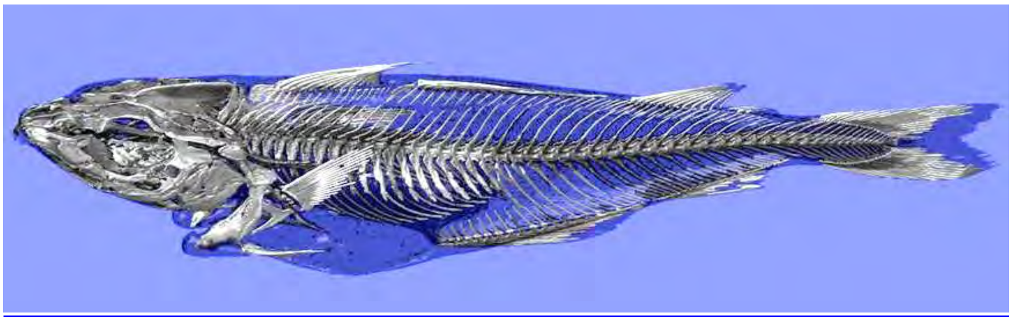
Report

Apricot 2

CT imaging of whole fish and fillets

Authors
Marianne Bakken
Helene Schulerud



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SINTEF IKT
SINTEF ICT

Address:
Postboks 124 Blindern
NO-0314 Oslo
NORWAY

Telephone:+47 73593000
Telefax:+47 22067350

postmottak.IKT@sintef.no
www.sintef.no
Enterprise /VAT No:
NO 948 007 029 MVA

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ABSTRACT

The objectives of this project have been to image bones in whole fish and fillets in 9 different species and to provide detailed information about the size, orientation and location of pinbones and the walking stick bone in fillets. For each species 2-4 fillets were CT scanned and analyzed. The bones and fillet were segmented and length, thickness, position and orientation of the pinbones were estimated.

Comparison with manual control measurements for some of the fillets showed that all the bones were detected, but there were some deviations in the length and thickness measures. These deviations were mainly due to limitations in CT resolution.

In this study we found that the species have a mean pinbone thickness between 0.6-1.1 mm and mean length between 9-48 mm.

We present in this report initial analysis of the data. However, the goal of this project has primarily been to assemble a relevant dataset as a basis for further analysis. To enable independent analysis, all data is made available electronically for download.

PREPARED BY Marianne Bakken	SIGNATURE
CHECKED BY Jens Thielemann	SIGNATURE
APPROVED BY Mats Carlin	SIGNATURE

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1 Objectives

The objectives of this project have been to image the bones in whole fish and fillets and to provide detailed information about the size, orientation and location of pinbones and the walking stick bones in selected species of filleted fish. This will provide new, detailed knowledge about the bone anatomy of whole fish and after filleting. The information should be of a quality that enable to:

- Identify new processing methods of whole fish (decapitation and filleting)
- Guidance for sensor selection and placement for precise 3D bone positioning
- Guidance for bone removal methods for different fish species
- Guidance for bone detection algorithms for different fish species

The goal of this project has been to assemble a relevant dataset as a basis for further analysis. This project builds on the previous project APRICOT anatomy.

2 Fish data

Norway Seafoods has provided whole fish and fillets of Cod, Haddock, Redfish, Catfish and Tusk, while Ling, Saithe, Catfish, Salmon, Redfish and Hake were purchased from Fiskcentralen in Oslo.

The fish have been selected such that it spans in size variation between small and medium size. The fish from Norway Seafood has been automatically filleted by a representative machine (Baader 184/185, Marel filleting machine MS 2730). We used untrimmed fillets with skin in this study. Fillets from Fiskecentralen were manually filleted. There was a large variation in the filleting quality from the Fiskcentralen, which resulted in extra or missing bones and problems with segmentation and automatic measurements. Fiskcentralen was not able to deliver Catfish or Ling with head, and Norway Seafoods had some delivery issues due to stormy weather. As a result, there are no CT scans of Ling with head, while there are scans of whole Catfish both with and without head.

Weight and length were registered for each fillet and fish. The data of the measured fish and fillets are shown in Appendix A2.

In order to ensure correct handling of the fish including related information, the following protocol was developed in collaboration with NOFIMA:

> Each fish was placed in a plastic bag and marked with ink with a unique identification tag. The tag is constructed by: The Species_Whole/Fillet_Number (e.g. HF_ 1 for Haddock fillet number 1). The fish and fillets were placed flat in a plastic bag, so it could be CT scanned directly in the bag.

Figure 1. Image of fish and fillet before Ct scanning.

3 Acquisition method

3.1 Setup

The fish (with plastic bag) was placed on a plastic plate before scanning. To make it easier to segment and remove the plate and bottom of the scanner in the images afterwards, the imaging area was chosen within the edge of the plate, with good margins to the fish, as illustrated in Figure 2. The fish was scanned head first.

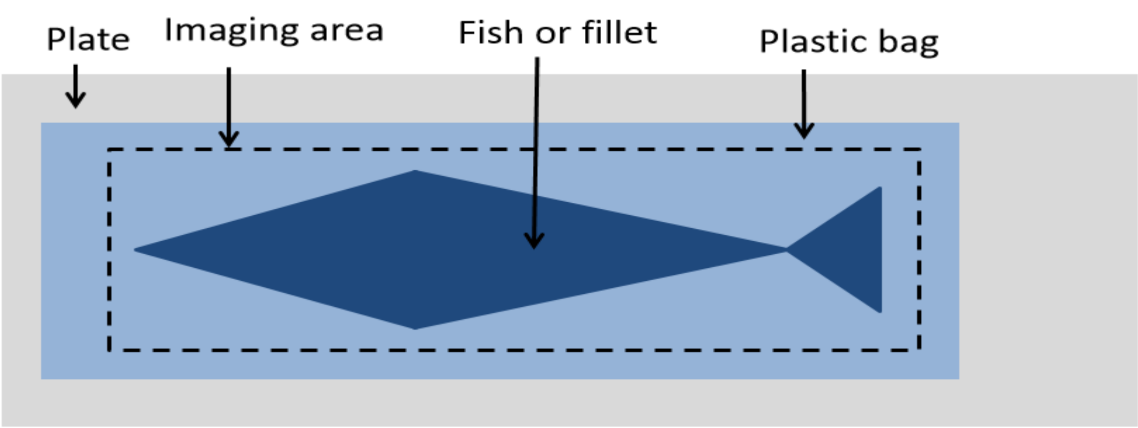


Figure 2. Illustration of setup with fish, plastic bag and plate.

3.2 CT acquisition parameters

We used Toshiba Aquilion One CT machine at Rikshospitalet for image acquisition. The following parameters were used:

- CT scan parameters
  - KVP: 80 kV
  - Slice thickness: 0.50 mm
  - X-ray tube current: 580 mA
  - Scan option: Helical CT
  - Exposure time 1 s
- CT reconstruction parameters
  - Overlap 0.4
  - Reconstruction diameter: varies from fish to fish
- Data format
  - Format: Dicom
  - Width: 512
  - Height: 512
  - Bit depth: 16

Resolution of CT scans:

- X direction (along the fish): 0.4 mm. Results from slice thickness of 0.5 mm with 0.4 overlap.
- Z, Y direction: 0.24-0.52 mm. Varies from fish to fish, because the reconstruction diameter varies with the width of the fish fillets.

3.3 Data acquisition

The following fish and fillets were CT scanned:

1. CT scanning 12.2.2016
   a. 4 whole fish and 4 fillets of Cod
   b. 4 whole fish and 4 fillets of Haddock

2. CT scanning 19.2.2016
   a. 4 whole fish and 4 fillets of Tusk
   b. 4 whole fish and 4 fillets of Ling
   c. 4 whole fish and 4 fillets of Saith
   d. 2 whole fish and 2 fillets of Catfish
3. CT scanning 28.2.2016
   a. 4 whole fish and 4 fillets of Salmon
   b. 2 whole fish and 2 fillets of Hake
   c. 4 whole fish and 4 fillets of Redfish
   d. 2 whole fish of Catfish

The CT scans were saved as images in DICOM format. The acquisition plan is shown in Appendix A2.

4 Method

4.1 Pinbone measurement

In order to verify the CT measurements of the pinbone sizes, bones were manually measured for 3 Cod, 2 Salmon, 2 Saithe, 2 Haddock, 1 Ling, 2 Catfish, 2 Hake and 3 Redfish fillets.

The bones were removed after CT scanning and measured manually by slide caliper. The bone thickness was measured at the center of the bone and the length of the bones was measured in a straight line between the ends. The shape of the fish bone is not always round, but have a more elliptic shape. This results in that the bones often have one thick and one thinner side. We measured the thickness in the thinnest direction.

4.2 Data segmentation

The DICOM images were analyzed in MATLAB. The bones and fillet/fish were segmented out in order to provide data suited for further analysis and extraction of high-level information and visualization. The segmentation was done through the following procedure:

1. Segment the plate by detecting its surface in each slice, and performing a piecewise linear plane fitting. All content below the plate is marked as background and removed from the image.
2. Segment the fillet from the air and plastic by means of simple intensity thresholding. Manual marking was necessary to remove remaining plastic in some cases.
3. Bone segmentation is performed with several steps:
    a. Remove the surface of the fillet by dilation of the background
    b. Adaptive threshold for bone detection
    c. Apply opening operation in 3D on all thresholded data to remove noise
4. Manually mark the pinbones and walking stick bone in the thresholded image, in order to remove other bones and noise before bone measurements.

Steps 1-3 was performed both for the fillets and the fish. Step 4 was only for the fillets.

Due to high variation in skin and fillet intensity values between the species, the bone segmentation parameters had to be adapted for each species. This was especially the case for the whole fish.

4.3 Fillet bone information

For the fillets, we have extracted high level information about the bones from the segmented data. The orientation, position, length and size were computed for pinbones and the walking stick bone. Other bones were detected, but not measured.

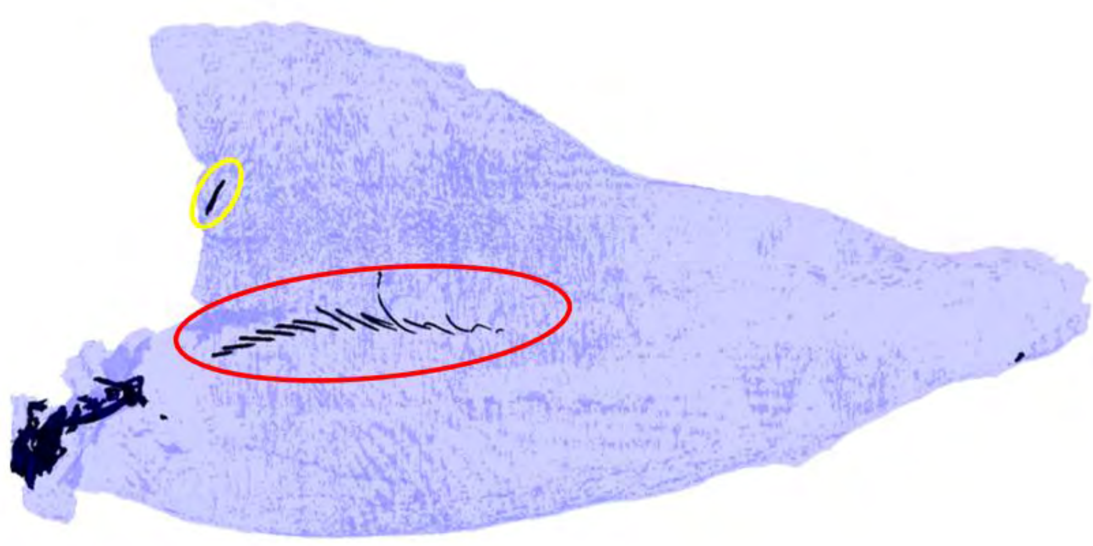


Figure 3. Illustration of pinbones (red) and walking stick (yellow).

4.3.1 Bone length and thickness

The length of each bone has been measured through the following procedure:

1. The XYZ position of all the voxels within the bone has been extracted, and put into a 3xN matrix
2. Principal component analysis has been used to rotate the bone such that its primary direction is parallel to the X-axis
3. The points have been sorted according to position along X-axis, and the 0-5% leftmost and 95-100% rightmost have been extracted, and the average XYZ of these two clusters have been extracted.
4. The length of the bone is defined as the Euclidean distance between these two clusters.

The thickness of each bone has been measured through the following procedure:

1. Steps 1 & 2 have been repeated
2. The points have been sorted according to position along X-axis, and the points on the middle (40-60 percentile) have been extracted. The average YZ position of these points have been calculated, and the distance of each point to this average point has been calculated. The thickness has been calculated as the 98 percentile of these distances.

4.3.2 Extraction of bone position and orientation

The fish bone position was calculated through the following procedure:

1. The fish was positioned and aligned by calculating a linear transforms that:
   a. Orients the Z-axis such that it is normal to the planar surface the fish is laying on, and such that Z=0 is equal to this planar surface, and such the fish is primarily in the space Z > 0.
   b. Aligns the X-axis such that is aligned with the dominating direction of the fish (the longest direction)
   c. Positions X=0 such that it is at the start of the fish, and Y=0 such that it is in the middle of the fish.

   This transform has been calculated through primarily principal component analysis.
2. Steps 1-3 in section have been used to establish start and end point for the bone. These points are transformed back into the axis system defined in point 1 above, and are reported according to this coordinate system. The start position is defined as the point closest to Z=0.
3. After this, these points are transformed such that they are in the coordinate system defined in point 1 above
4. The start and end position (according to the coordinate system defined in 1) is reported as the fish bone's position. Similarly, the vector between start and end is reported as the fish bone's normal.

To calculate the fish bone's orientation, we map the fish bone's normal into each of the planes XY, YZ and XZ. We then measure (in degrees) the angle between the fish bone's normal and respectively the X, Z and Z axis.

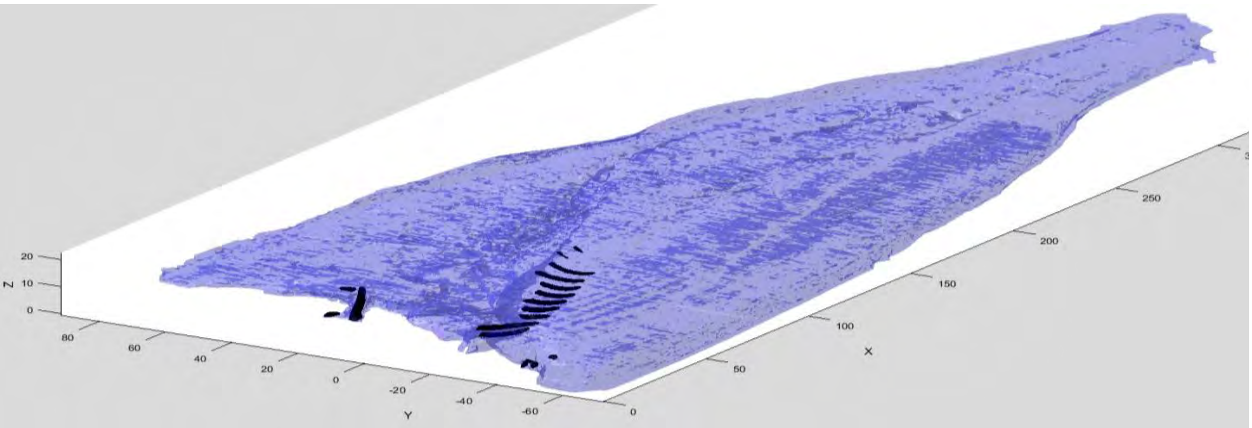


Figure 4. Processed CT image of a Haddock fillet (HFM1) with x, y, z -axis and detected bones.

4.4 Loin height profiles

A rough estimate of the loin profiles were computed by measuring the maximum fillet height along the longitudinal axis of the fillet, and applying a mean filter to remove noise. This can be used as a starting point for further estimation of the volume of the loin. An example of a loin profile is shown in Figure 5.

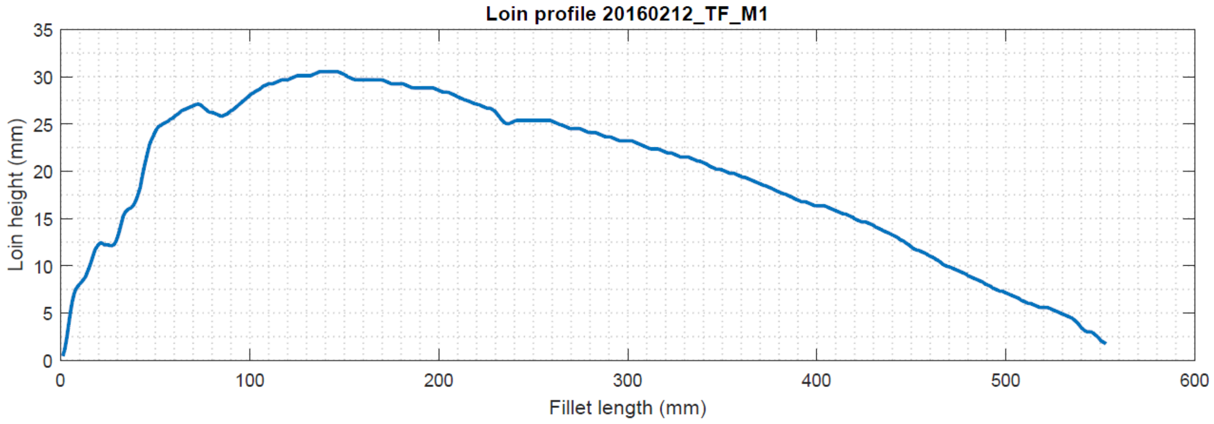


Figure 5. Loin profile for Cod TF_M1.

4.5 3D models of whole fish and fillets

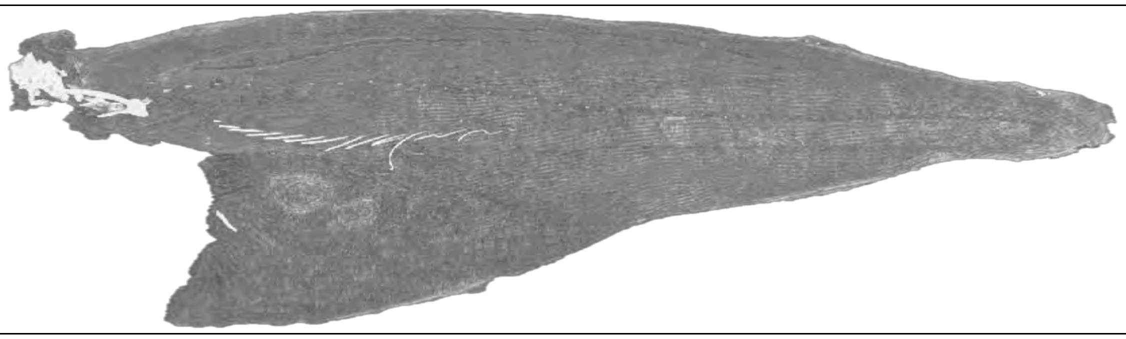
To compute 3D surfaces of the bones and fillet/fish from the CT images, isosurfaces were computed directly from the volume data. Results from the segmentation were used as masks in this operation to remove the plate and fish/fillet edge. The bones shown in the 3D models may therefore have a slightly different thickness and lengths of the bones than the segmented data that was used for bone measurements.

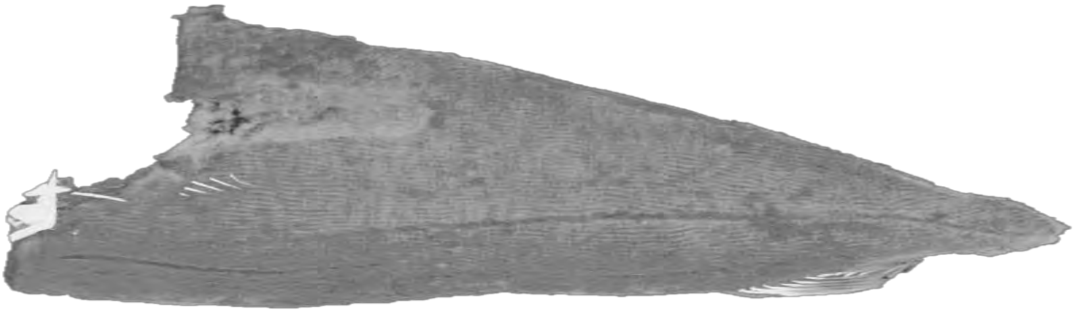
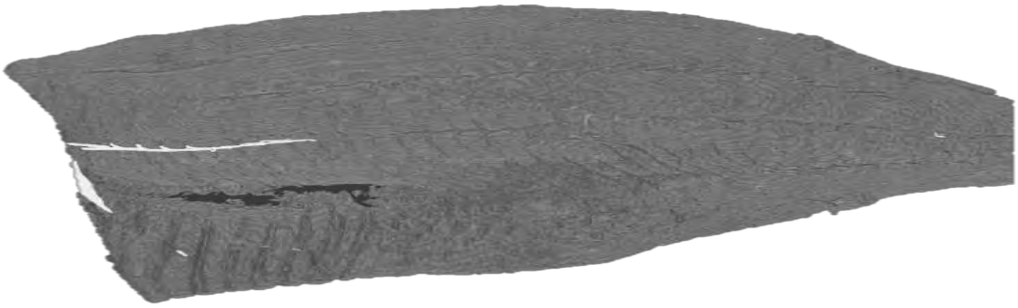
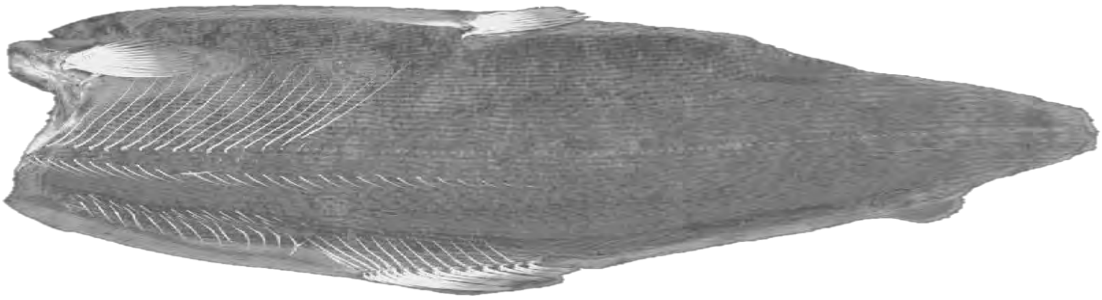
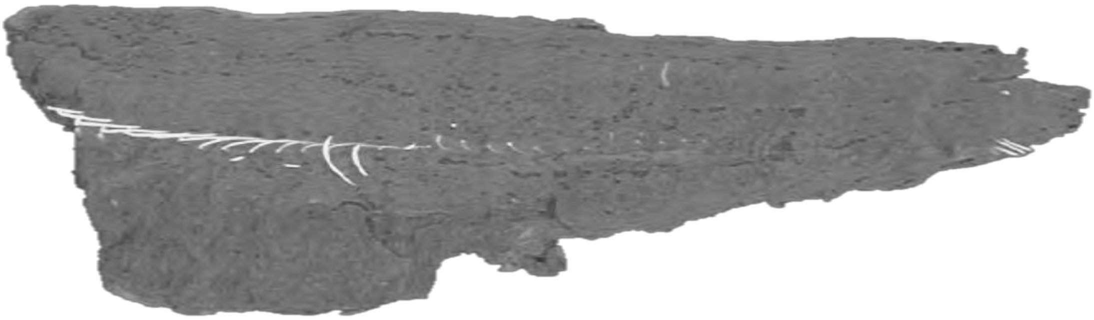
5 Results

5.1 CT scan images

Example CT images of fillets and whole fish for each species are shown below. The images show the intensity values seen from above, after segmentation and removal of the plate.

Due to large variation in the data, a few fish and fillets failed in the different processing steps, even after adaption per species. Fishing hooks and bended plate are some examples of artefacts that made the algorithms fail. This applies to one Salmon and one Ling for whole fish and two Tusk and one Saithe for the fillets. These cases are missing bone measurements and/or 3D visualization.

Cod (TFM1)	

Haddock (HFS1)	
Saithe (SF2)	
Salmon (LXF2)	
Tusk (BF1)	

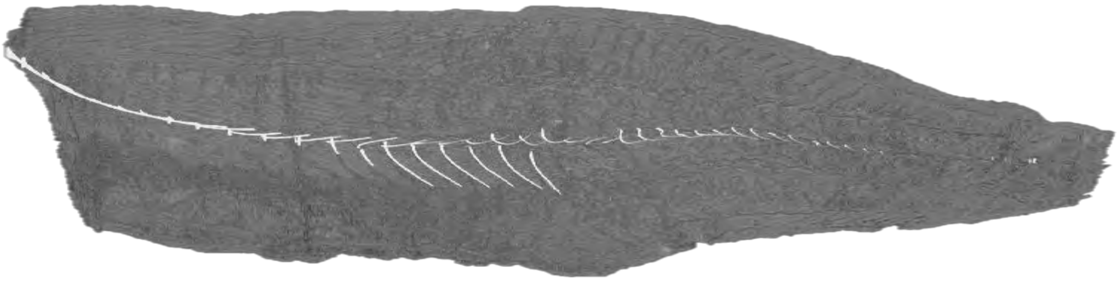
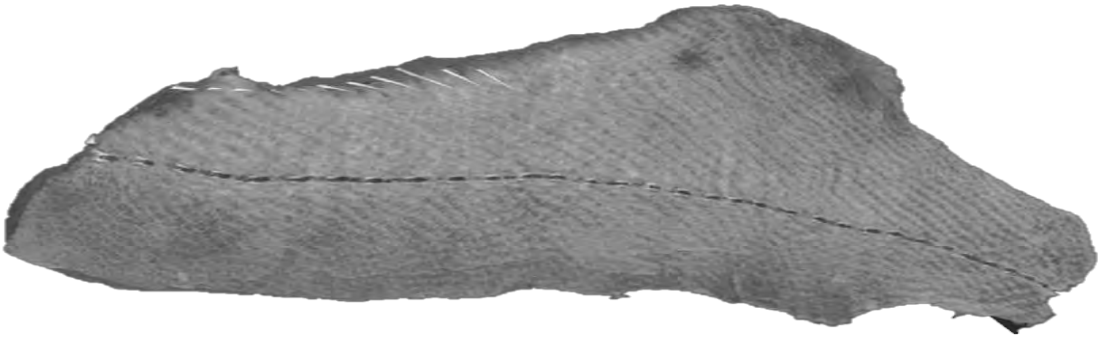
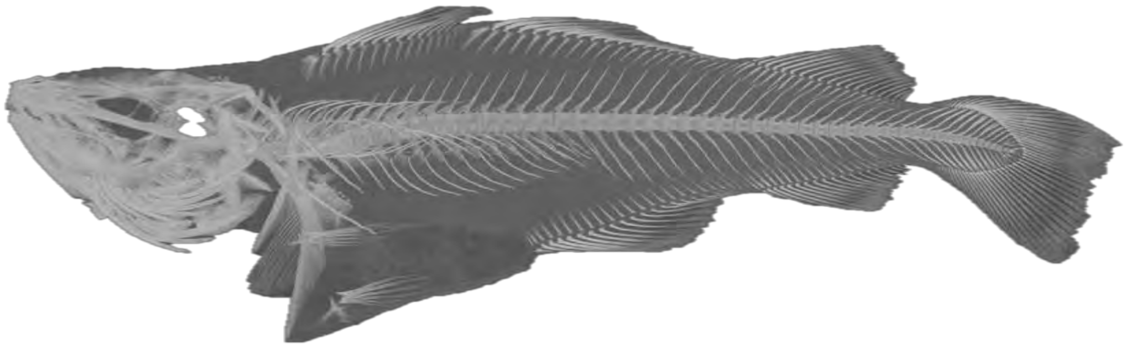
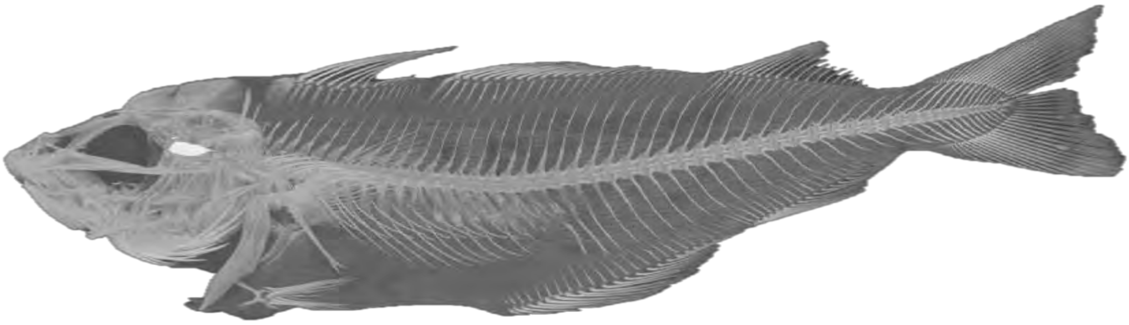
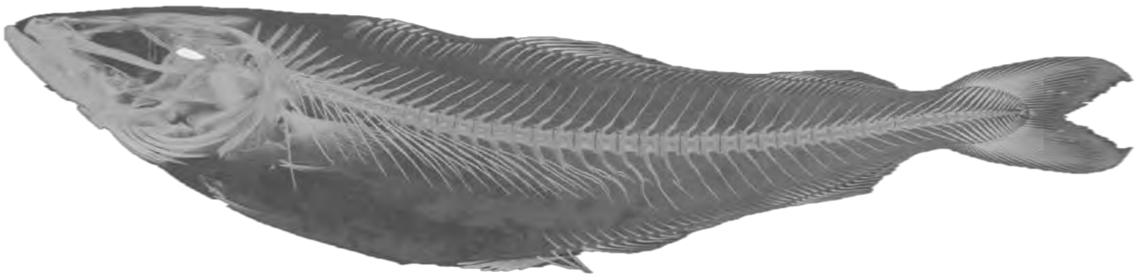
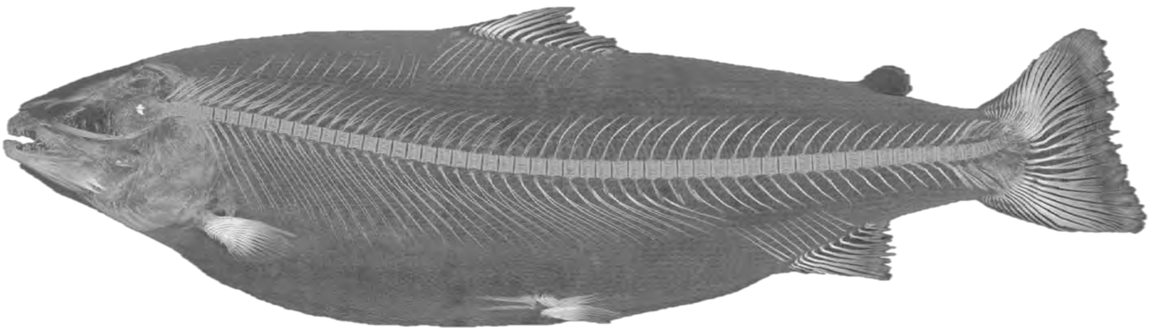
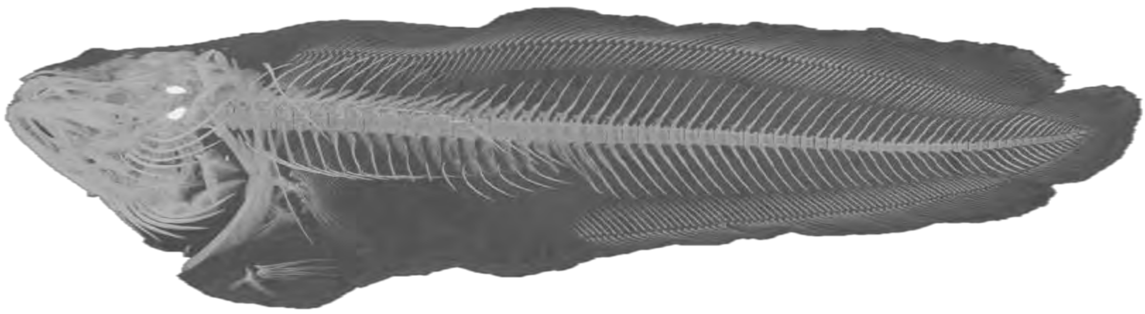
Ling (LF1)	
Catfish (STF2)	
Hake (LYF2)	
Redfish (UF1)	

Figure 6. Example CT images of fillets for each species.

Cod (THS2)	
Haddock (HHM2)	
Saithe (SH2)	
Salmon (LXH2)	
Tusk (BH2)	

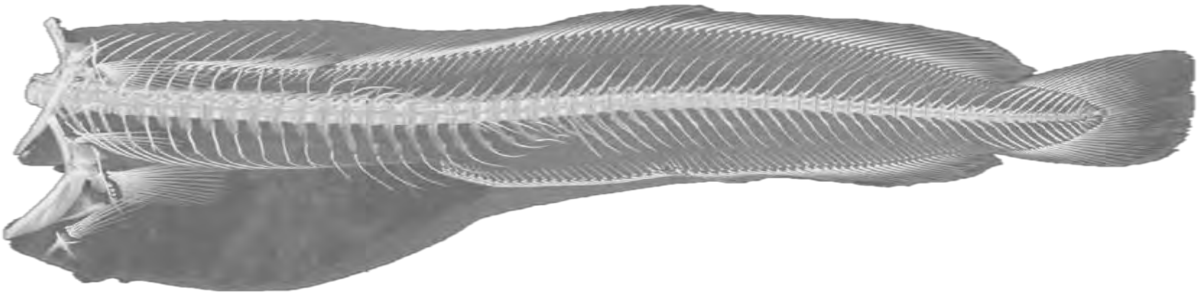
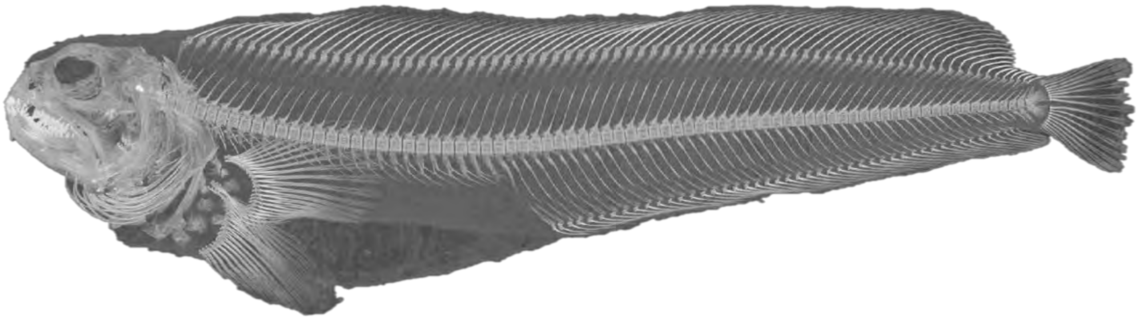
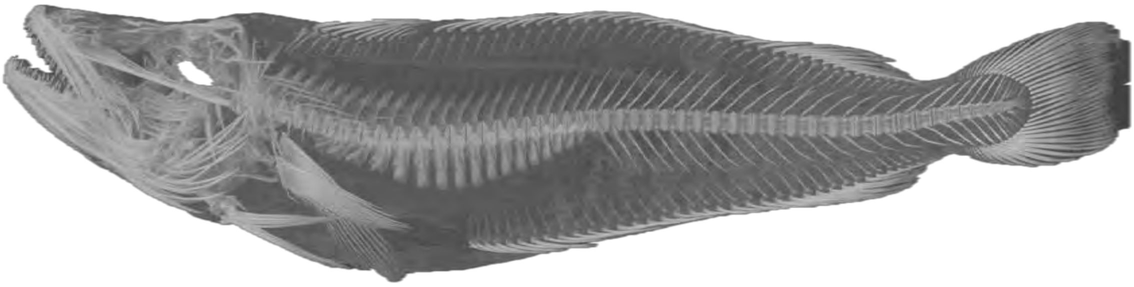
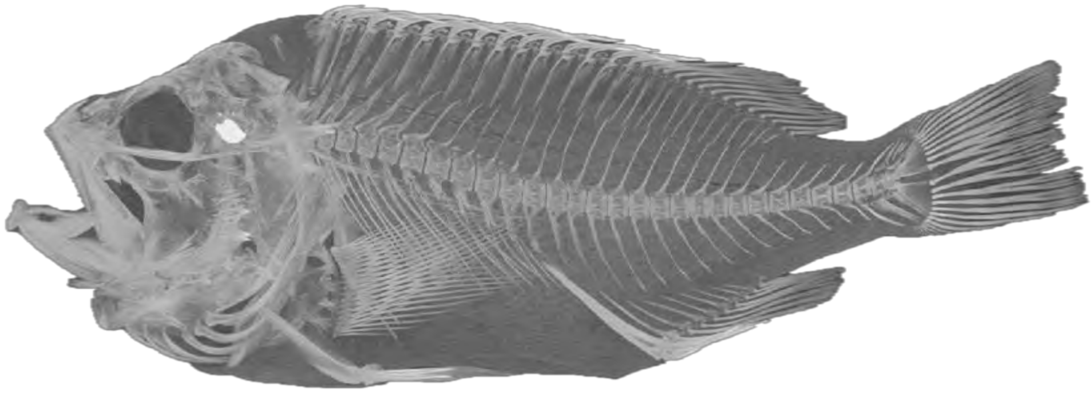
Ling (LH3)	
Catfish (STH2)	
Hake (LYH1)	
Redfish (UH2)	

Figure 7. Example CT images of whole fish for each species.

5.2 Bone detection

All detected bones in fillets and fish are visualized in 3D from different viewpoints in Appendix B and in videos at the Apricot 2 eroom, se Appendix A1 for detailed information. An example of detected bones in a fillet is shown in

Figure 8 .

Additionally, separate visualizations of numbered pinbones are provided in 3D_pinnbones.pdf file at the Apricot 2 eroom.

As thin bones and fins have almost the exact same intensity values as fish skin in the CT images, it is difficult to detect these when they are close to the skin. There is also an unclear transition between cartilage and bones. These two effects are especially seen in the visualization of the whole fish.

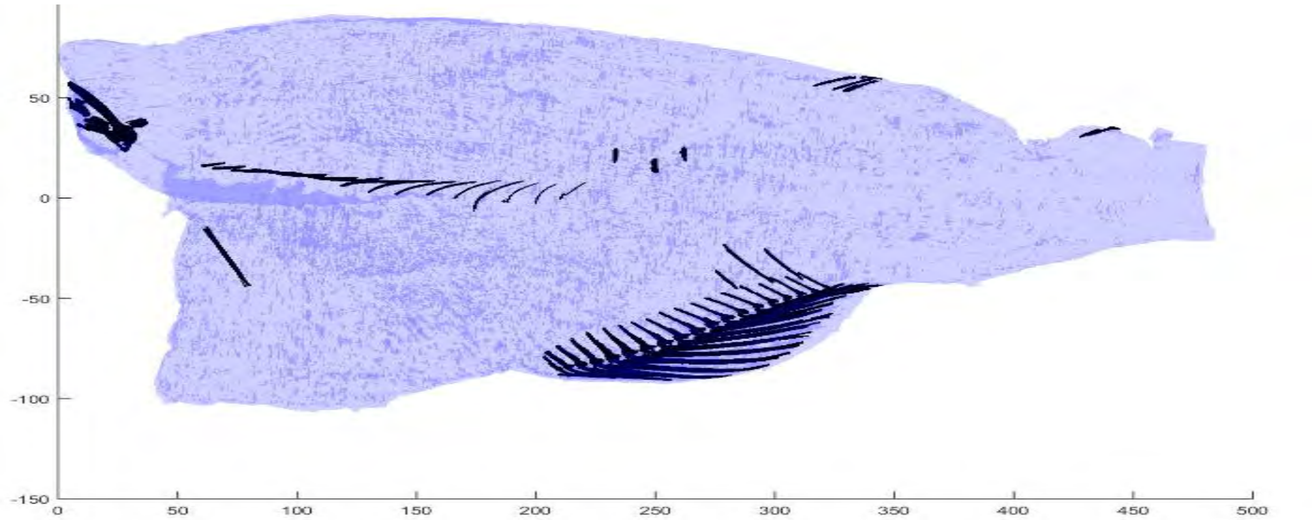


Figure 8. Example of detected bones.

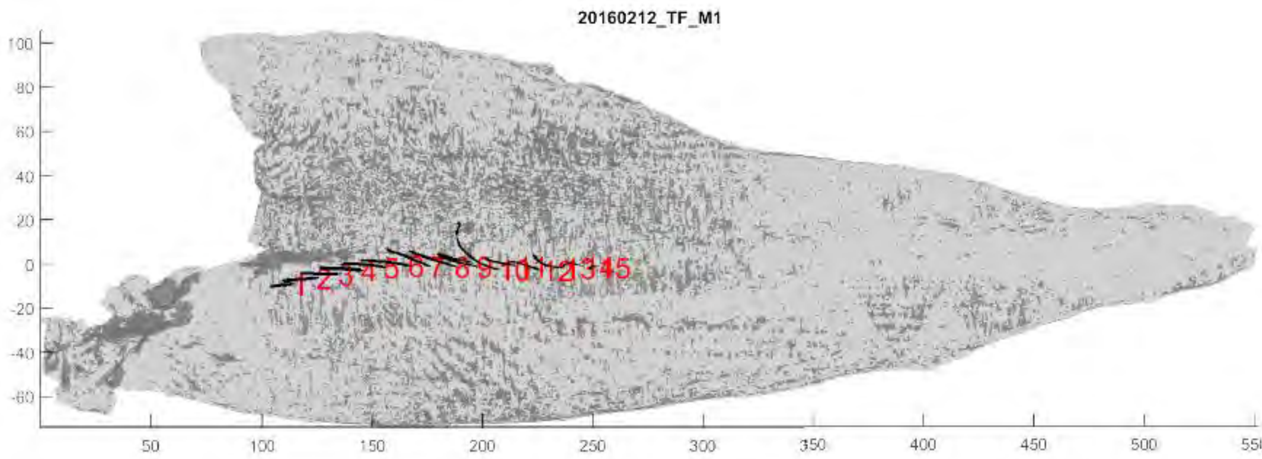


Figure 9. Example of pinbone visualization.

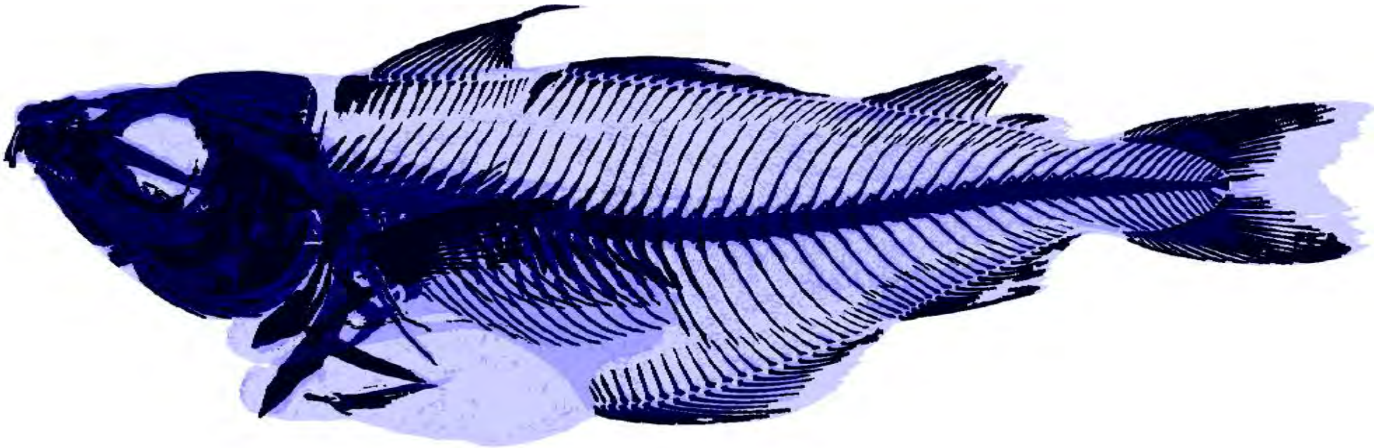


Figure 10. Example of visualization of Haddock skeleton.

5.3 Comparison of CT and manually measured pinbone sizes

The fillets were analysed and the bones were segmented and automatically measured. The CT bone measures were compared with the manually measured bone length and thickness, see Appendix A4.

Table 1 shows the mean values and standard deviations of the differences between manual control measurements and CT measurements of pinbones for all the fish spices. The mean difference between the measured thickness of the pinbones in the CT image and the manually measures, differs from 0.02mm to 0.26mm (previous study gave 0.1mm to 0.3 mm) for the different spices.

Figure 11 shows that the CT pinbone measures in general gives 0.2 mm thicker bones than the manual measures, independent of the pinbone thickness.

The mean difference between the measured lengths in the CT image and manual control measures ranges between 0.4 mm for Cod and Ling to 12.4 mm for Salmon. This corresponds to previous results. The largest deviations occur in Salmon, which is mainly due to the long thin ends of the Salmon pinbones. These thin ends are not imaged by the CT scanner, because of resolution limitations. Since the Salmon fillets were wide, the CT resolution was about 0.5mm, while for thinner fillets the resolution was around 0.2mm.

Figures for each fillet with CT and manually measured length and thickness are shown in Appendix A4.

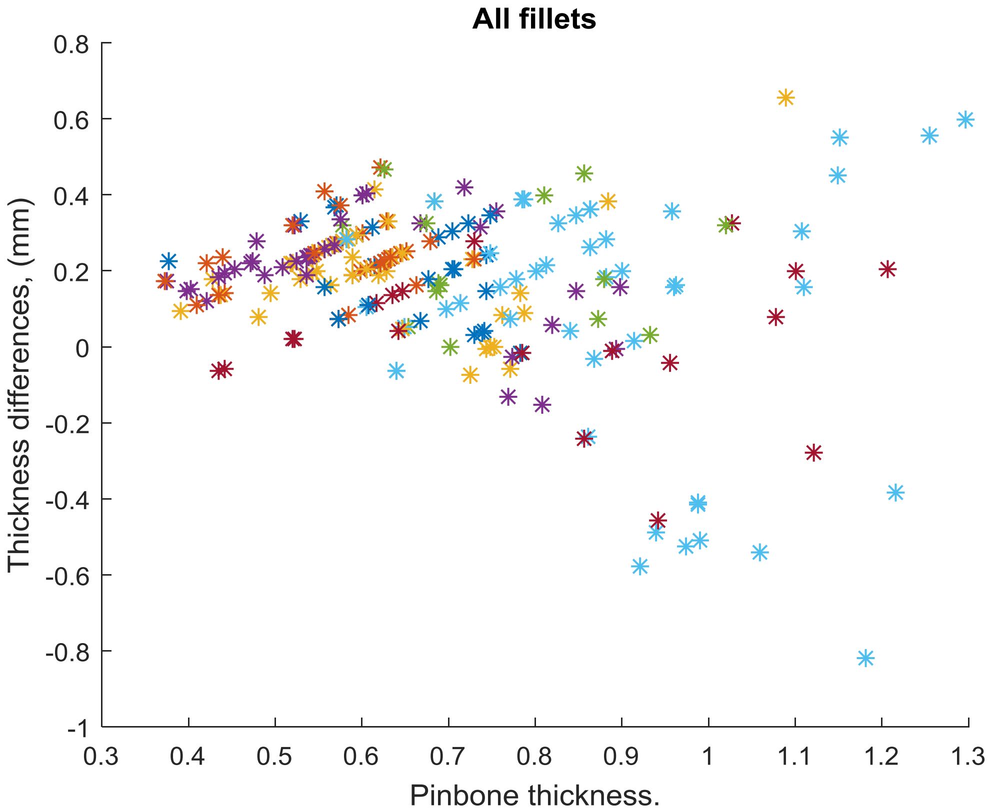


Figure 11. Differences between measured lengths in the CT image and manual control measures as a function of pinbone thickness.

Fish	Fillet id	Mean difference length (mm)	Std of difference length (mm)	Mean difference thickness (mm)	Std difference thickness (mm)
Haddock	HF_M1	-2.02	1.13	0.14	0.10
Haddock	HF_S1	-4.20	1.18	0.26	0.14
Cod	TF_M1	-2.16	4.37	0.16	0.21
Cod	TF_M2	-1.19	6.61	0.17	0.21
Cod	TF_S1	-0.42	6.07	0.23	0.16
Ling	LF1	-0.41	8.78	0.03	0.36
Saith	SF2	-0.62	6.52	-0.02	0.24
Catfish	STF1	-1.79	3.87	0.27	0.08
Catfish	STF2	-2.45	3.59	0.24	0.06
Salmon	LXF2	-8.66	5.66	0.20	0.07
Salmon	LXF3	-12.40	5.51	0.22	0.06

Hake	LYF1	-2.47	12.12	0.24	0.17
Hake	LYF2	-3.13	2.45	0.25	0.16
Redfish	UF1	-1.38	2.29	0.07	0.10
Redfish	UF2	-1.39	5.27	0.22	0.12
Redfish	UF3	-3.23	2.08	0.23	0.10
Total mean		-2.99	4.84	0.18	0.15

Table 1. Differences between manual control measures and CT measures of pinbone length and thickness.

5.4 Pinbone measurements

The tables below shows the pinbone measurements from the CT data. For all fillets, the number of pinbones as well as minimum, maximum and mean values of pinbone thickness and length are reported in Table 2. Orientation and position are reported in Table 3.

A summery of the pinbone statistics for each species are given in Table 4.

Fillet id	No. bones	Length (mm)			Thickness (mm)		
		Min	Max	Mean	Min	Max	Mean
HF_M1	11	3.7	31.6	16.8	0.4	0.8	0.7
HF_M2	7	16.5	26.6	21.0	0.5	1.0	0.7
HF_S1	5	3.2	10.8	8.5	0.6	0.6	0.6
HF_S2	4	9.9	21.9	13.8	0.5	2.2	1.0
TF_M1	15	9.0	31.3	20.0	0.5	1.1	0.7
TF_M2	16	9.5	29.4	22.2	0.5	0.9	0.7
TF_S1	14	9.2	30.5	17.6	0.3	0.8	0.6
TF_S2	13	12.0	25.5	19.3	0.5	0.9	0.7
BF2	25	5.7	30.4	18.9	0.4	1.4	0.7
BF4	25	5.3	24.1	13.6	0.4	0.8	0.6
LF1	42	6.8	57.3	36.7	0.6	1.3	0.9
LF2	38	8.7	68.6	37.8	0.7	1.7	0.9
LF4	38	0.5	71.8	36.1	0.5	1.7	0.9
SF1	10	12.0	62.0	46.3	0.7	4.2	1.3
SF2	10	40.3	53.3	48.4	0.8	1.2	1.0
SF4	12	4.2	45.5	32.4	0.5	2.4	0.9
STF1	24	6.9	15.3	12.5	0.4	0.7	0.6

STF2	26	5.0	17.3	12.2	0.4	0.7	0.5
LXF1	28	13.5	32.1	24.8	0.5	1.0	0.6
LXF2	28	4.8	25.8	18.9	0.4	0.6	0.6
LXF3	26	7.8	19.2	13.8	0.3	0.6	0.5
LXF4	31	8.1	21.0	17.2	0.4	0.7	0.6
LYF1	9	31.3	46.0	39.9	0.7	1.4	0.9
LYF2	10	17.9	38.8	32.2	0.6	1.1	0.8
UF1	11	4.6	22.9	12.6	0.4	0.7	0.6
UF2	6	11.3	31.3	21.4	0.6	0.7	0.7
UF3	8	9.0	16.7	12.7	0.4	0.6	0.5
UF4	9	9.8	17.1	13.9	0.4	0.6	0.5

Table 2. Extracted pinbone information for the fillets; Number of bones, length and thickness

Fillet id	**Orientation**			**Position (mm)**	
	YZ mean	**XZ mean**	**XY mean**	**X start (first bone)**	**Length of bone area in x direction**
HF_M1	13.0	67.2	173.9	21.7	84.6
HF_M2	9.7	62.8	175.4	76.1	68.9
HF_S1	48.8	70.3	159.1	50.3	21.9
HF_S2	60.0	71.8	149.1	66.8	33.6
TF_M1	18.3	54.8	167.3	103.9	148.8
TF_M2	21.1	61.7	164.9	59.9	161.4
TF_S1	26.2	58.0	162.0	101.8	137.4
TF_S2	26.3	58.8	148.8	92.7	130.1
BF2	18.8	29.3	121.3	31.8	197.4
BF4	22.4	41.1	24.7	137.2	186.9
LF1	27.6	45.2	150.6	2.5	627.8
LF2	21.3	58.0	167.1	8.8	670.1
LF4	16.0	59.5	170.6	9.5	692.5
SF1	9.2	61.2	175.1	22.8	132.5
SF2	5.8	62.4	177.0	33.3	139.5
SF4	19.0	64.6	172.3	13.4	109.0
STF1	25.1	57.2	163.3	2.2	160.9
STF2	28.9	58.8	163.8	17.3	167.2

LXF1	35.7	54.9	148.7	25.6	243.7
LXF2	37.5	53.4	150.1	6.0	216.6
LXF3	28.1	46.5	152.5	10.4	174.9
LXF4	43.0	53.7	145.6	11.6	237.4
LYF1	41.7	61.4	151.8	106.3	104.5
LYF2	28.9	60.9	160.9	82.5	94.5
UF1	30.3	69.3	166.3	175.6	109.4
UF2	53.0	64.0	149.9	167.6	49.0
UF3	42.7	58.6	150.9	101.7	45.4
UF4	48.3	66.6	155.7	95.8	58.3

Table 3. Extracted pinbone information for the fillets; Orientation and position

Species	Mean no of bones	Min no of bones	Max no of bones	Mean bone Thickness (mm)	Min bone Thickness (mm)	Max bone Thickness (mm)	Mean bone Length (mm)	Min bone Length (mm)	Max bone Length (mm)
Cod	15	13	16	0,7	0,3	1,1	19,9	9,0	31,3
Haddock	7	4	11	0,7	0,4	2,2	15,9	3,2	31,6
Saithe	11	10	12	1,1	0,4	4,2	41,7	4,2	62,0
Salmon	28	26	31	0,6	0,3	1,0	18,7	4,8	32,1
Tusk	25	25	25	0,7	0,4	1,7	16,3	5,3	68,6
Ling	39	38	42	0,9	0,5	4,2	36,9	0,5	71,8
Catfish	25	24	26	0,6	0,4	1,0	12,3	4,8	32,1
Hake	10	9	10	0,9	0,4	1,4	35,8	4,6	46,0
Redfish	9	6	11	0,6	0,4	0,7	14,6	4,6	31,3

Table 4. Statistics on number of bones, thickness and length for different species.

5.5 Walking stick bone measurements

The walking stick bone was only present in some fillets. An overview of detected walking stick bones is given in Table 5.

For the fillets containing a walking stick bone, the thickness, length, orientation and position measured from the CT data is reported in Table 6.

Fillet ID	Number of fillets with walking stick	Length walking stick (mean, mm)
Haddock	3	19,4
Cod	3	19,4
Saithe	3	35,3
Salmon	0	-
Tusk	0	-
Ling	0	-
Catfish	0	-
Hake	0	-
Redfish	2	6,7

Table 5. Summary of detected walking stick bones for different species.

Fillet ID	Length (mm)	Thickness (mm)	Start position (mm)			Orientation (degrees)		
			x	y	z	yz	xz	xy
HF_M1	25,1	1,7	33,3	22,9	1,6	85,3	87,5	28,4
HF_M2	16,9	1,2	73,7	-34,5	1,5	88,3	87,6	54,4
HF_S1	16,2	0,7	34,7	5,3	1,1	24,7	72,2	171,6
TF_M1	13,5	1,1	101,3	39,5	1,8	89,0	88,7	52,1
TF_M2	32,5	1,6	62,0	-15,9	2,9	85,1	82,2	58,0
TF_S1	12,7	1,0	108,6	36,6	0,3	72,7	79,6	149,4
SF1	38,1	1,1	90,5	-67,3	4,9	86,1	87,2	144,7
SF3	39,7	1,2	62,5	59,0	3,6	83,6	81,9	127,9
SF4	28,2	1,0	53,2	-36,9	3,6	89,0	88,2	120,1
UF1	2,5	1,5	310,7	15,4	17,6	1,6	53,8	178,9
UF2	11,0	2,1	87,7	40,4	0,8	57,7	86,9	175,1

Table 6. Walking stick properties measured from CT data (for fillets with walking stick present).

5.6 Loin height profile

The loin height profiles for all fillets are provided in Appendix C.
The loin thickness (maximum height of the loin profile) are summarized for each species in Table 7.

Species	Loin thickness		
	Mean (mm)	Min (mm)	Max (mm)
Haddock	19,7	15,2	23,2
Cod	27,4	23,4	30,5
Tusk	28,2	24,3	31,2
Ling	37,5	36,5	38,1
Saithe	30,7	26,1	35,3
Catfish	16,7	16,6	16,8
Salmon	30,3	27,7	34,4
Hake	26,9	24,7	29,2
Redfish	22,3	16,4	28,2

Table 7. Statistics for loin thickness (measured at its thickest) for different species.

6 Summary

The objectives of this project have been to image bones in whole fish and fillets in 9 different species and to provide detailed information about the size, orientation and location of pinbones and the walking stick bone in fillets. For each species 2-4 fillets were CT scanned and analyzed. The bones and fillet were segmented and length, thickness, position and orientation of the pinbones were estimated.

Comparison with manual control measurements of the pinbones showed that all the bones were detected in the CT images, but there were some differences in the length and thickness measurements. The CT measures gives some higher thickness (0.2 mm) while the CT measured length was 3 mm shorter. This is mainly due to limitations in resolution of the CT scanner. The thin ends of the bones are below the resolution of the CT images. There was only small differences between the species regarding the pinbone thickness differences, while for pinbone length in Salmon the difference between CT and manual measures was higher than for the other spices.

The resolution depends on the width of the fillet, and all large fillets (> 1 kg) with high width is scanned with lower resolution which results in to short estimates of the pinbone length.

In this study we found that all the species have a mean pinbone thickness between 0.6-1.1 mm, the mean number of bones detected in this study compared to the previous study was 11 (7) for Saithe and 7 (7) for Haddock, 15 (13) for Cod and 28 (29) for Salmon. The differences are due to the variation in fillet sizes measured.

We present in this report initial analysis of the data. However, the goal of this project has primarily been to assemble a relevant dataset as a basis for further analysis. To enable independent analysis, all data is made available electronically for download. All images and analyzed data are available at an eroom, see Appendix A1 for more details.

A Fish and fillet data

A.1 Fish and fillet data at eroom

All the CT images in Matlab format, detected bones and fillet in PLY format together with statistics of estimated features of the pinbones are available for downloading from the eroom Apricot anatomy (https://project.sintef.no/eRoom/ikt2/Apricotanatomy).

Anyone who is interested will be invited into this eroom by contacting Marianne Bakken (email: marianne.bakken@sintef.no) or Helene Schulerud (email: hsc@sintef.no).

Overview of data at the eroom

- Rawdata.zip: Raw CTscanner data (int16) in Matlab format.
- Apricot2Data.zip: contains one folder for each fillet/fish with the following files
    - bone.stl: Mesh of bones in stl format for import into CAD software
    - fish.stl: Mesh of fillet in stl format for import into CAD software
    - patches.mat: 3D surfaces of bone and fish in MAT format (suitable for later plotting and processing in Matlab through i.e. patch command)
    - For fillets only:
        - stats.mat: Matlab file containing measured lengths, orientations etc per pinbone in the fillet, and overall statistics per fillet. Same statistics for walking stick bone where applicable.
        - segmented.mat: Matlab file with the following variables:
            - info: Raw DICOM info for the captured data
            - resolution: Resolution in XYZ (in mm) for captured data
            - segmented: Segmented data. The following values are used:
                - 0: Background (non-fish)
                - 10: Fish meat
                - 101-150: Each bone is given an individual number in this range
            - xform: Transformation matrix from calibration
- 3D_fillets.pdf: 3D rendering of fish fillets
- 3D_fish.pdf: 3D rendering of whole fish
- 3D_pinbones.pdf: 3D rendering and numbering of pinbones (fillets only)
- Loin_profiles.pdf: Profile of loin thickness for each fillet (fillets only)
- Fillet_videos: 3D rendered fillets shown in videos
- Fish_videos: 3D rendered fish shown in videos

- Allstats.xls: Minimum, maximum and mean of pinbone length, thickness, orientation and the start point of the first bone and the stop position of the last bone.
  Sheets:
    - Name – name of species and fillets ID
    - All stats- statistics for pinbone measure pr fillet
    - Bone_length – bone lengths for all fillets
    - Bone_thicness – bone thicness for all fillets
    - Stat - statistics for pinbone measures pr spices
    - Manually_bone_thichness – manually measured pinbone thickness
    - Manually_bone_length – manually measured pinbone length

- Readme.txt: text file describing the content in the different files.

A.2 Fish and fillet data

Whole fish ID	Fillet ID	Species	Weight (g)	Length (cm)	Left/ right fillet	Comment	Delivered by	Scan date
TH-M1		Cod (Torsk)	3260	73	-		Norway Seafoods	12.2.2016
TH-M2		Cod (Torsk)	3531	81	-		Norway Seafoods	12.2.2016
TH-S1		Cod (Torsk)	1799	66	-		Norway Seafoods	12.2.2016
TH-S2		Cod (Torsk)	2214	68	-		Norway Seafoods	12.2.2016
	TF-M1	Cod (Torsk)	904	60	l		Norway Seafoods	12.2.2016
	TF-M2	Cod (Torsk)	1105	50	r		Norway Seafoods	12.2.2016
	TF-S1	Cod (Torsk)	593	55	l		Norway Seafoods	12.2.2016
	TF-S2	Cod (Torsk)	807	60	r		Norway Seafoods	12.2.2016
HH-M1		Haddock (Hyse)	1734	61	-		Norway Seafoods	12.2.2016
HH-M2		Haddock (Hyse)	1898	63	-		Norway Seafoods	12.2.2016
HH-S1		Haddock (Hyse)	925	48	-		Norway Seafoods	12.2.2016
HH-S2		Haddock (Hyse)	779	48	-		Norway Seafoods	12.2.2016
	HF-M1	Haddock (Hyse)	515	43	l		Norway Seafoods	12.2.2016
	HF-M2	Haddock (Hyse)	608	44	r		Norway Seafoods	12.2.2016
	HF-S1	Haddock (Hyse)	230	31	r		Norway Seafoods	12.2.2016
	HF-S2	Haddock (Hyse)	210	34	l		Norway Seafoods	12.2.2016
BH-1		Tusk (Brosme)	4065	72	-		Norway Seafoods	19.2.2016
BH-2		Tusk (Brosme)	3718	72	-		Norway Seafoods	19.2.2016
BH-3		Tusk (Brosme)	1516	61	-		Norway Seafoods	19.2.2016
BH-4		Tusk (Brosme)	731	43	-		Norway Seafoods	19.2.2016
	BF-1	Tusk (Brosme)	369	37	l		Norway Seafoods	19.2.2016

Whole fish ID	Fillet ID	Species	Weight (g)	Length (cm)	Left/ right fillet	Comment	Delivered by	Scan date
	BF-2	Tusk (Brosme)	537	38	l		Norway Seafoods	19.2.2016
	BF-3	Tusk (Brosme)	507	36	r		Norway Seafoods	19.2.2016
	BF-4	Tusk (Brosme)	296	37	r		Norway Seafoods	19.2.2016
LH-1		Ling (Lange)	4859	86		Without head	Fiskcentralen	19.2.2016
LH-2		Ling (Lange)	3271	81		Without head	Fiskcentralen	19.2.2016
LH-3		Ling (Lange)	2770	71		Without head	Fiskcentralen	19.2.2016
LH-4		Ling (Lange)	2019	63		Without head	Fiskcentralen	19.2.2016
	LF-1	Ling (Lange)	3668	84	l		Fiskcentralen	19.2.2016
	LF-2	Ling (Lange)	3013	96	r		Fiskcentralen	19.2.2016
	LF-3	Ling (Lange)	2542	81	r		Fiskcentralen	19.2.2016
	LF-4	Ling (Lange)	3281	97	l		Fiskcentralen	19.2.2016
SH-1		Saithe (Sei)	2019	70			Fiskcentralen	19.2.2016
SH-2		Saithe (Sei)	1920	68			Fiskcentralen	19.2.2016
SH-3		Saithe (Sei)	1815	64			Fiskcentralen	19.2.2016
SH-4		Saithe (Sei)	1987	67			Fiskcentralen	19.2.2016
	SF-1	Saithe (Sei)	1687	63	r		Fiskcentralen	19.2.2016
	SF-2	Saithe (Sei)	1769	63	l		Fiskcentralen	19.2.2016
	SF-3	Saithe (Sei)	693	50	l		Fiskcentralen	19.2.2016
	SF-4	Saithe (Sei)	690	50	r		Fiskcentralen	19.2.2016
STH-1		Atlantic catfish (Steinbit)	1840	66		Without head	Fiskcentralen	19.2.2016
STH-2		Atlantic catfish (Steinbit)	2043	63		Without head	Fiskcentralen	19.2.2016

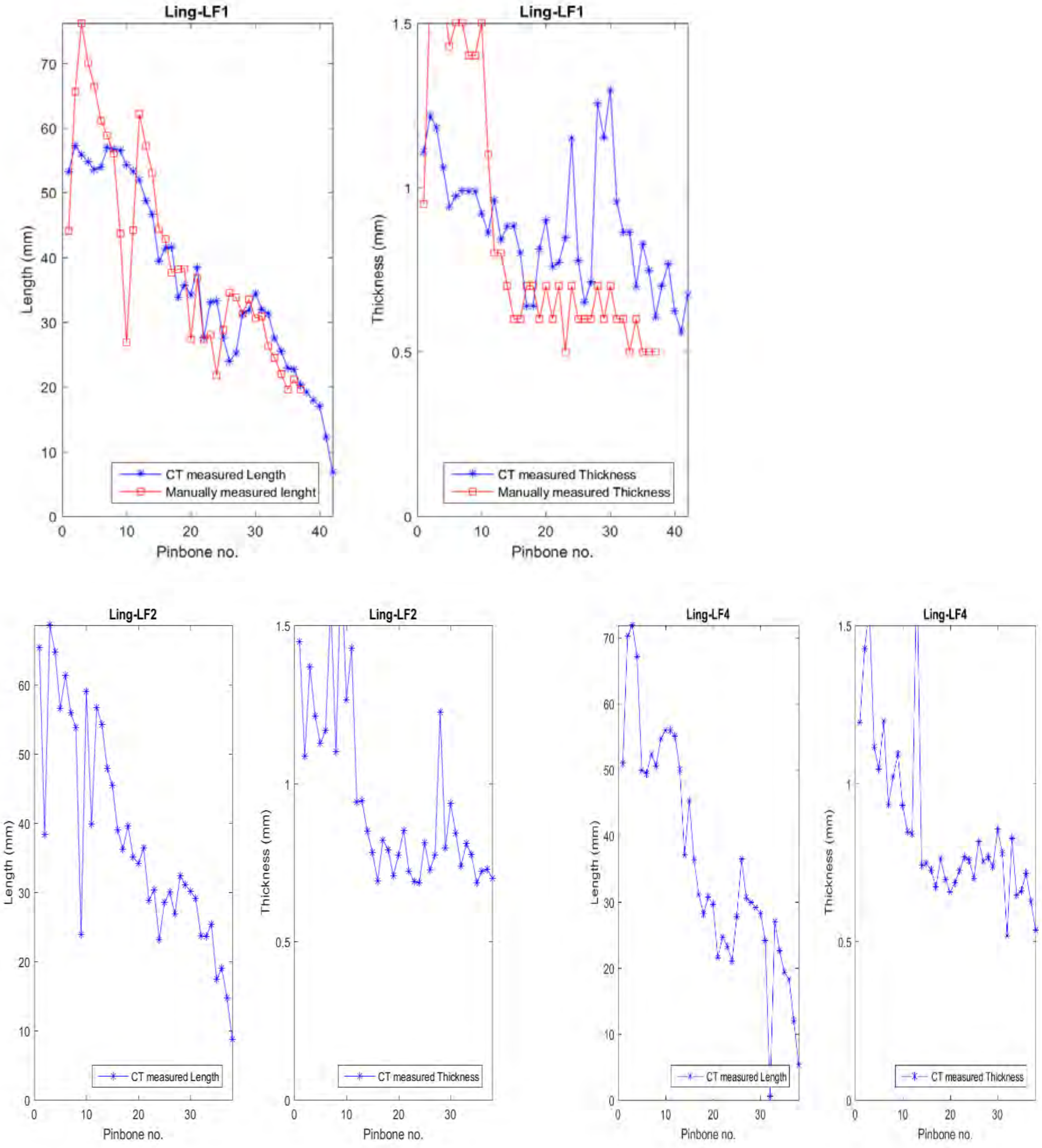
Whole fish ID	Fillet ID	Species	Weight (g)	Length (cm)	Left/ right fillet	Comment	Delivered by	Scan date
	STF-1	Atlantic catfish (Steinbit)	344	**50**	l		Fiskcentralen	19.2.2016
	STF-2	Atlantic catfish (Steinbit)	336	**50**	r		Fiskcentralen	19.2.2016
LXH-1		Salmon (Laks)	4217	68			Fiskcentralen	28.2.2016
LXH-2		Salmon (Laks)	4052	76			Fiskcentralen	28.2.2016
LXH-3		Salmon (Laks)	2389	63			Fiskcentralen	28.2.2016
LXH-4		Salmon (Laks)	2260	63			Fiskcentralen	28.2.2016
	LXF-1	Salmon (Laks)	1819	59	R		Fiskcentralen	28.2.2016
	LXF-2	Salmon (Laks)	1077	49	R		Fiskcentralen	28.2.2016
	LXF-3	Salmon (Laks)	754	43	L		Fiskcentralen	28.2.2016
	LXF-4	Salmon (Laks)	1034	49	L		Fiskcentralen	28.2.2016
LYH-1		Hake (Lysing)	2714	75			Fiskcentralen	28.2.2016
LYH-2		Hake (Lysing)	2462	76			Fiskcentralen	28.2.2016
	LYF-1	Hake (Lysing)	964	65	R		Fiskcentralen	28.2.2016
	LYF-2	Hake (Lysing)	682	57	L		Fiskcentralen	28.2.2016
UH-1		Redfish (Uer)	2837	56		Not gutted	Fiskcentralen	28.2.2016
UH-2		Redfish (Uer)	1742	53		Gutted at SINTEF	Fiskcentralen	28.2.2016
UH-3		Redfish (Uer)	3172	61		Not gutted	Fiskcentralen	28.2.2016
UH-4		Redfish (Uer)	737	39		Gutted at SINTEF	Fiskcentralen	28.2.2016
	UF-1	Redfish (Uer)	408	35	L		Norway Seafoods	28.2.2016
	UF-2	Redfish (Uer)	421	33	R		Norway Seafoods	28.2.2016
	UF-3	Redfish (Uer)	107	19	L		Norway Seafoods	28.2.2016

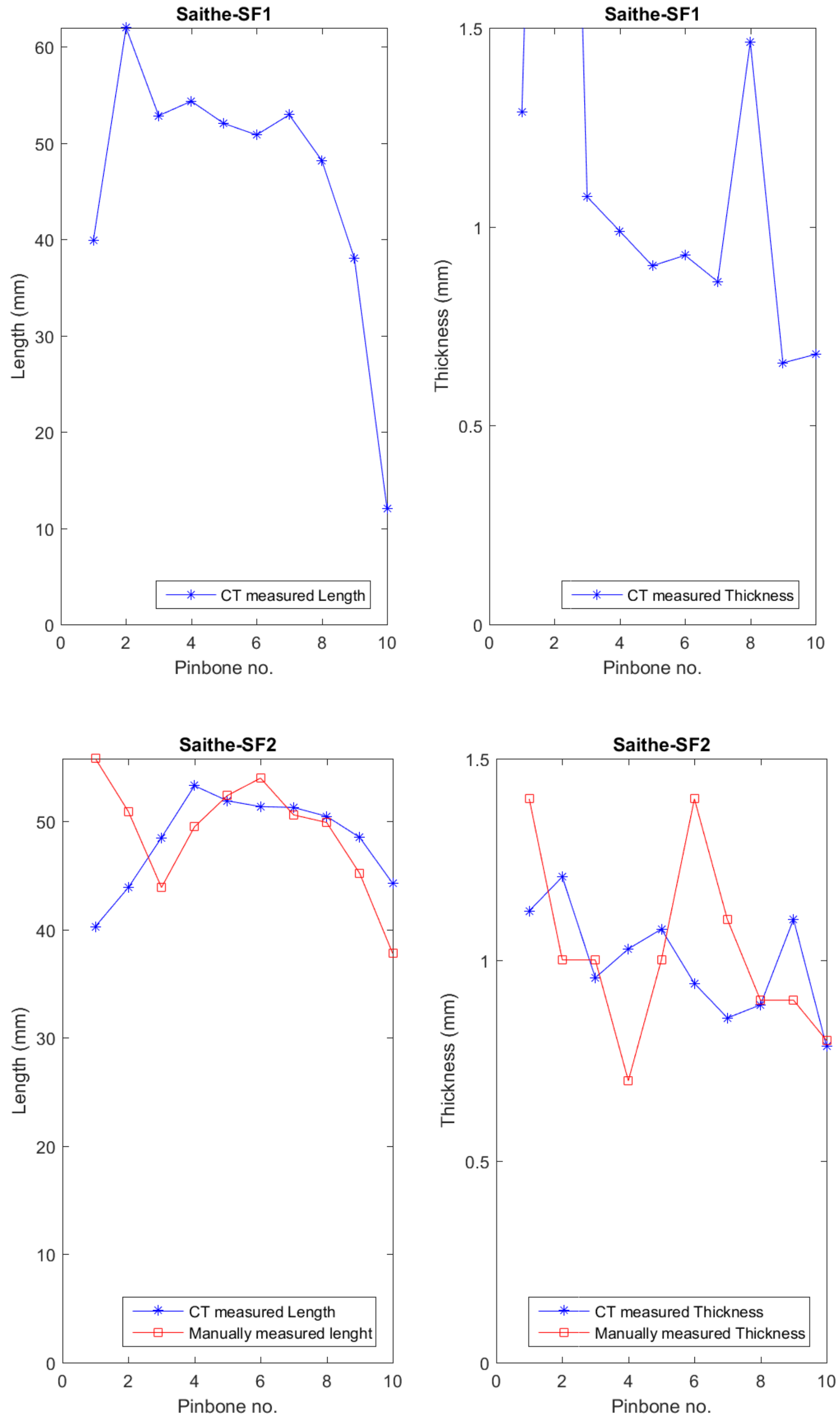
Whole fish ID	Fillet ID	Species	Weight (g)	Length (cm)	Left/ right fillet	Comment	Delivered by	Scan date
	UF-4	Redfish (Uer)	93	19	R		Norway Seafoods	28.2.2016
STHH-1		Catfish (Steinbit)	5000+	89		Flekksteinbit	Norway Seafoods	28.2.2016
STHH-2		Catfish (Steinbit)	3575	78		Flekksteinbit	Norway Seafoods	28.2.2016

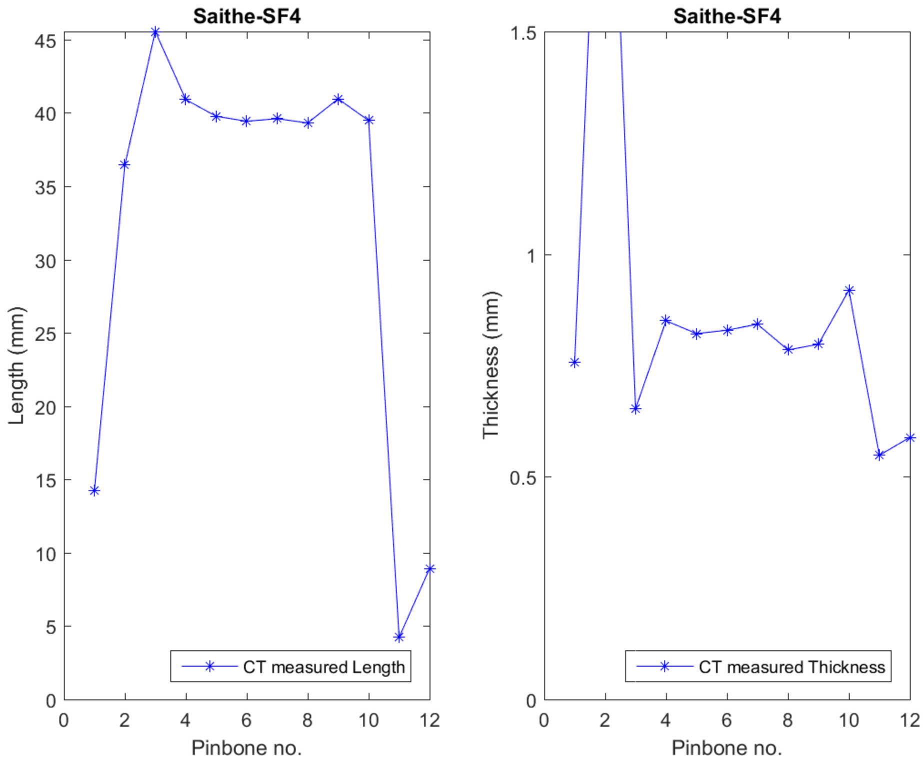
A.3 Sampling plan

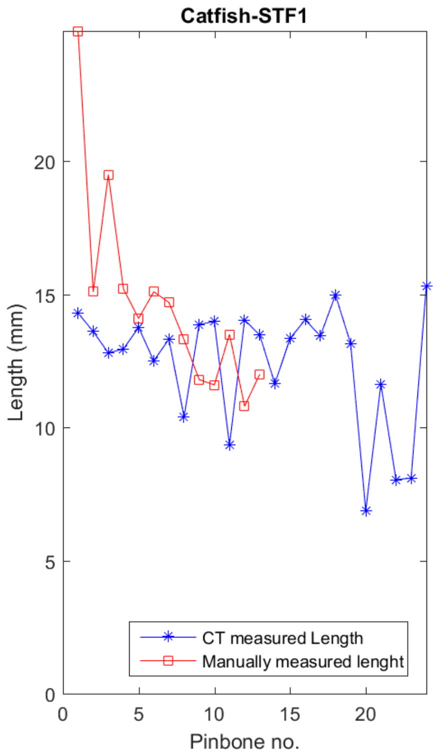
Batch	Specie (English)	Specie (Ice-landic)	Specie (Nor-wegian)	Scientific name	Whole fish	Size	Fillets (untrimmed/ with pinbones and spamannsbein)	Hrs
A	Cod	Þorskur	Torsk	Gadus morhua	2	M	2	1
A	Cod	Þorskur	Torsk	Gadus morhua	2	S	2	1
B	Haddock	Ýsa	Hyse	Melanogrammus aeglefinus	2	M	2	1
B	Haddock	Ýsa	Hyse	Melanogrammus aeglefinus	2	S	2	1
C	Saithe	Ufsi	Sei	Pollachius virens	2	M	2	1
C	Saithe	Ufsi	Sei	Pollachius virens	2	S	2	1
D	Tusk	Keila	Bromse	Brosme brosme	2	M	2	1
D	Tusk	Keila	Bromse	Brosme brosme	2	S	2	1
E	Ling	Langa	Lange	Molva molva	2	M	2	1
E	Ling	Langa	Lange	Molva molva	2	S	2	1
F	Blue ling	Blálanga	Blålange	Molva dypterygia	2	M	2	1
F	Atlantic catfish	Steinbítur	Steinbit	Anarhichas lupus	2	M	2	1
G	Atlantic salmon	Lax	Laks	Salmon salar	2	M	2	1
G	Atlantic salmon	Lax	Laks	Salmon salar	2	S	2	1
H	Deep sea redfish*)	Djúpkarfi		Sebastes mentella	2	M	2	1
H	European hake	Kolmúli/ lýsingur	Lysing	Merluccius merluccius	2	M	2	1
***) or E**	Redfish	Karfi	Uer	Sebastes marinus	4	M	4	2

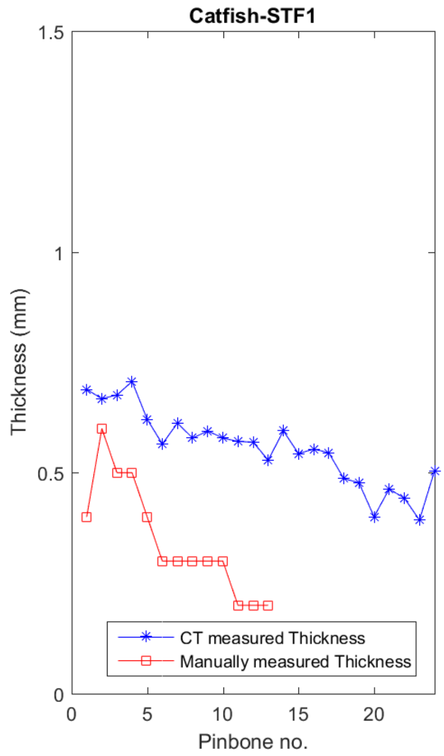
A.4 Comparison of CT and manually measures

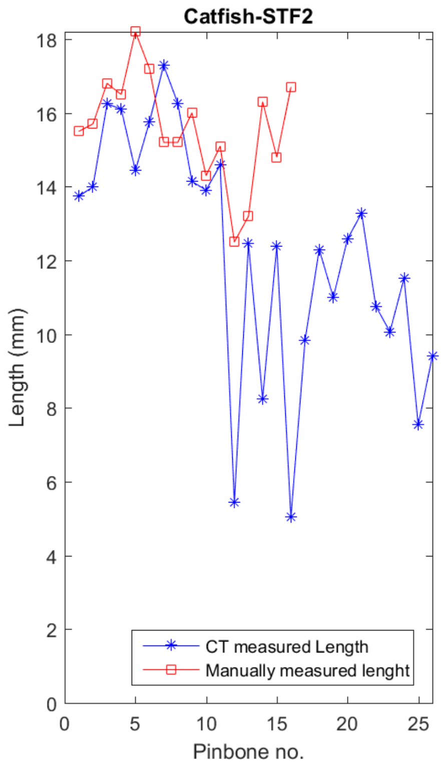


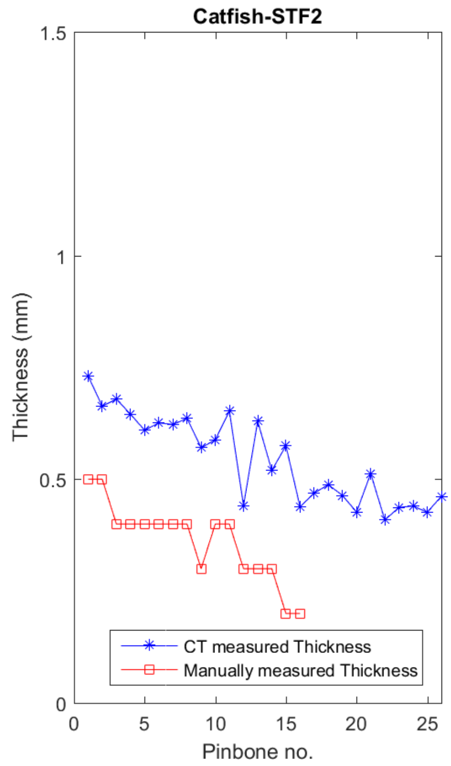

Saithe-SF1
Length (mm)
Pinbone no.
CT measured Length
Saithe-SF1
Thickness (mm)
Pinbone no.
CT measured Thickness
Saithe-SF2
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght
Saithe-SF2
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

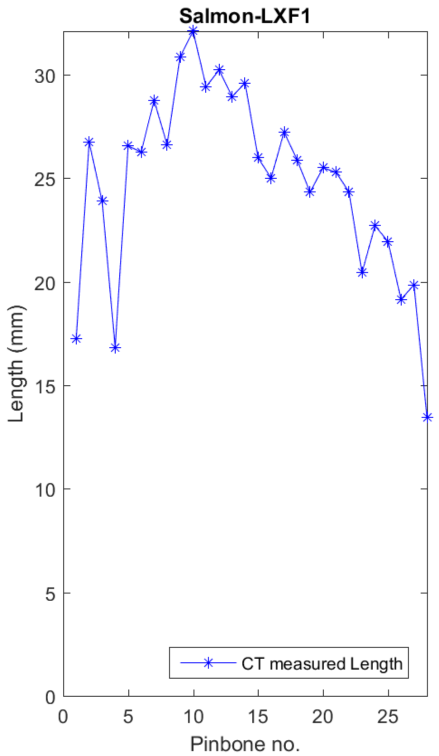

Saithe-SF4
Length (mm)
Pinbone no.
CT measured Length
Saithe-SF4
Thickness (mm)
Pinbone no.
CT measured Thickness

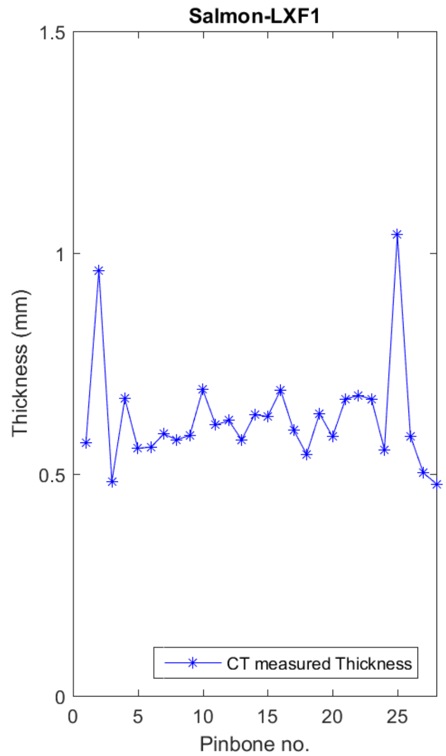

Catfish-STF1
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght

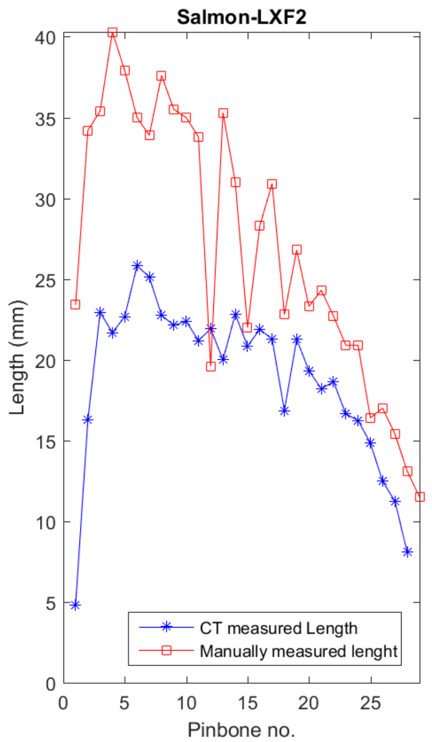

Catfish-STF1
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

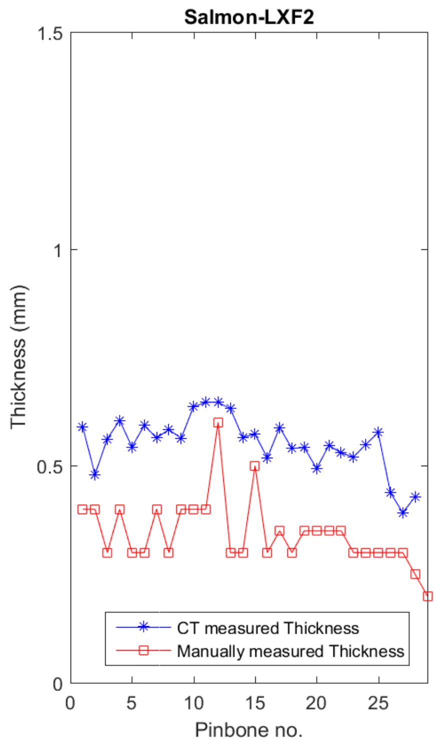

Catfish-STF2
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght

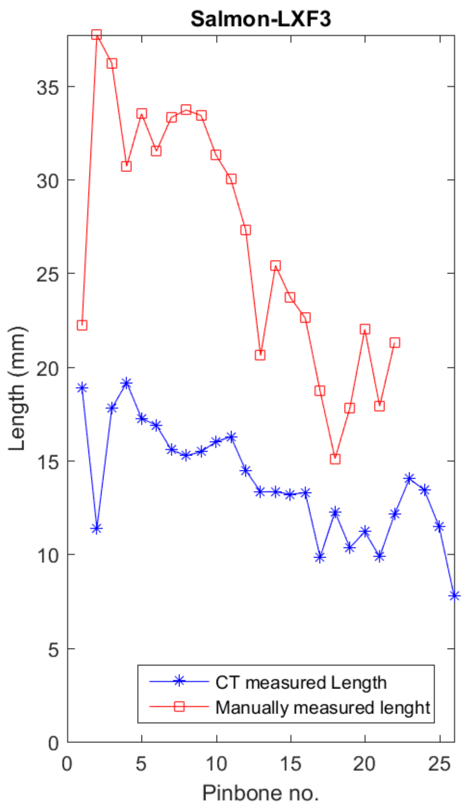

Catfish-STF2
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

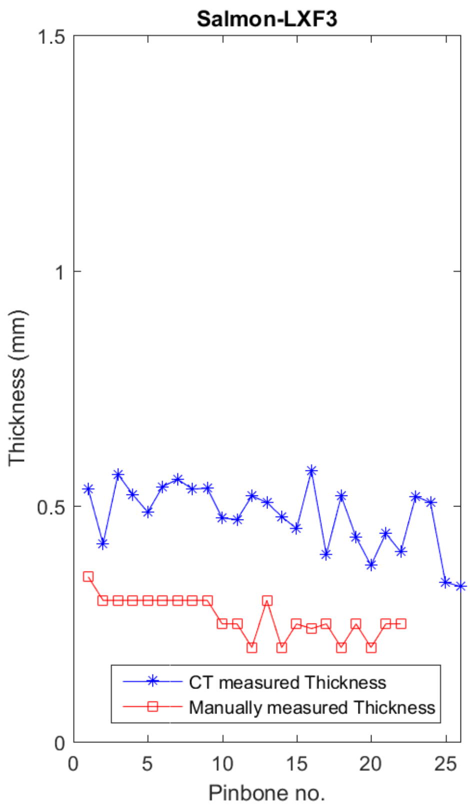

Salmon-LXF1
Length (mm)
Pinbone no.
CT measured Length


Salmon-LXF1
Thickness (mm)
Pinbone no.
CT measured Thickness


Salmon-LXF2
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght


Salmon-LXF2
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness


Salmon-LXF3
Length (mm)
35
30
25
20
15
10
5
0
0
5
10
15
20
25
Pinbone no.
CT measured Length
Manually measured lenght


Salmon-LXF3
Thickness (mm)
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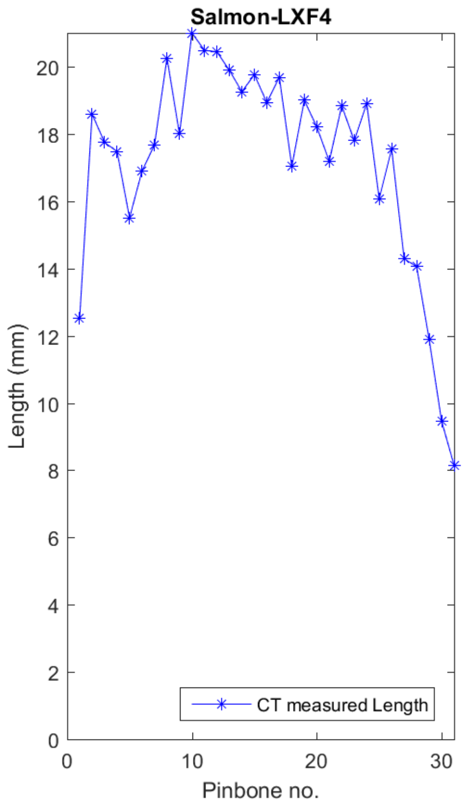
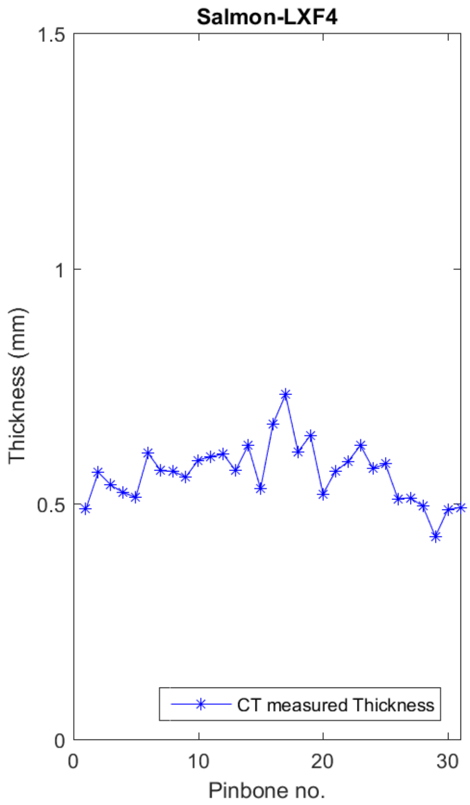
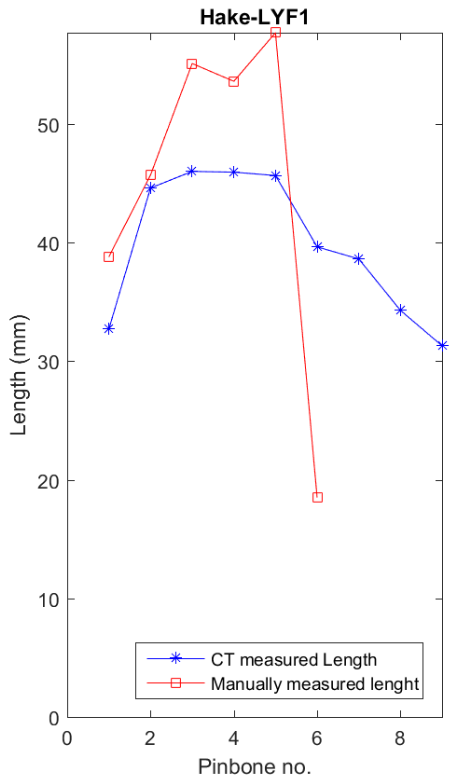
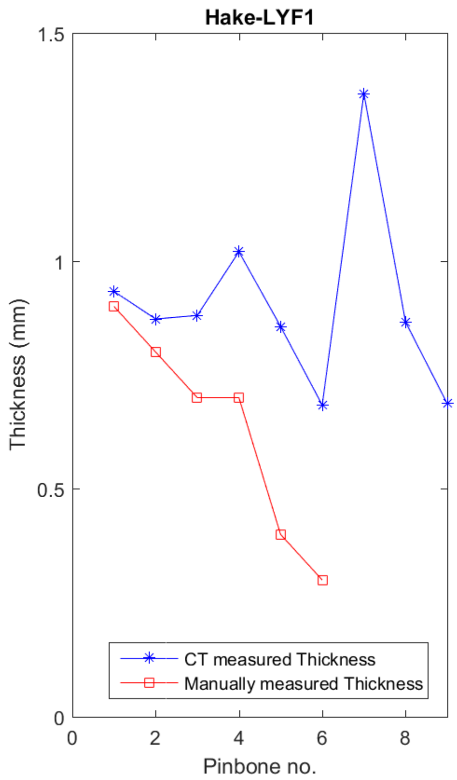
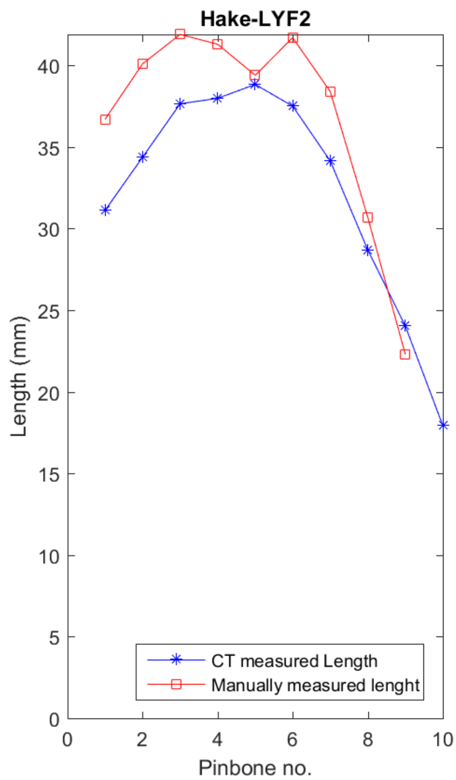
1
0.5
0
0
5
10
15
20
25
Pinbone no.
CT measured Thickness
Manually measured Thickness

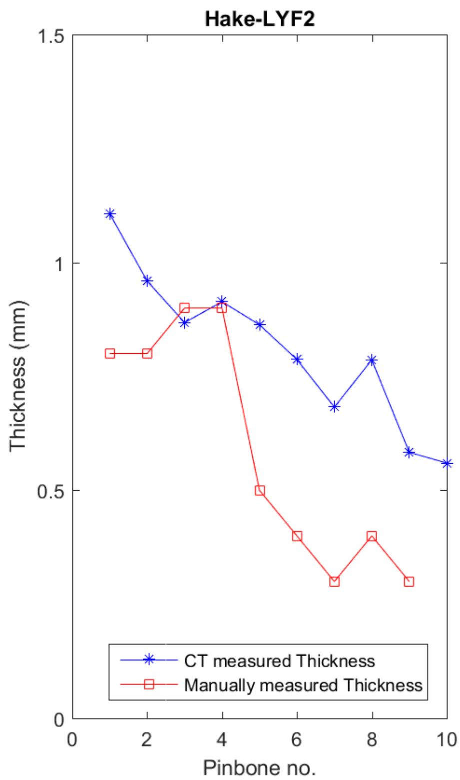

Salmon-LXF4
Length (mm)
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
Pinbone no.
CT measured Length

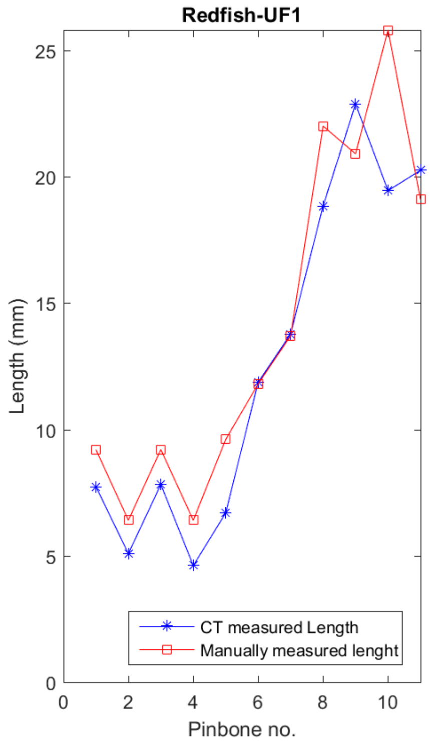

Salmon-LXF4
Thickness (mm)
1.5
1
0.5
0
0
10
20
30
Pinbone no.
CT measured Thickness

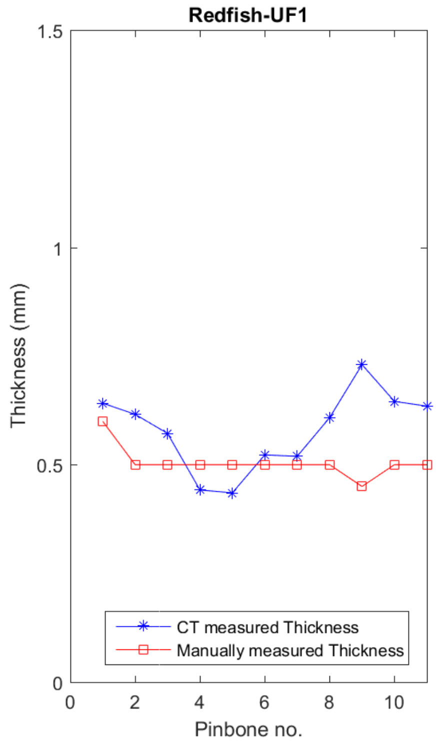

Hake-LYF1
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght

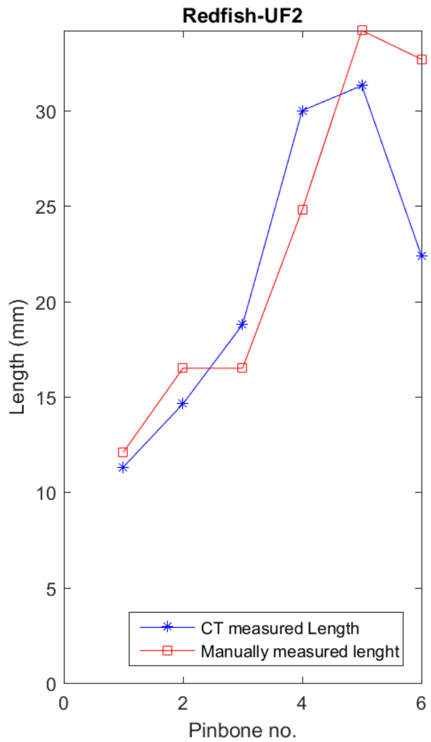

Hake-LYF1
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

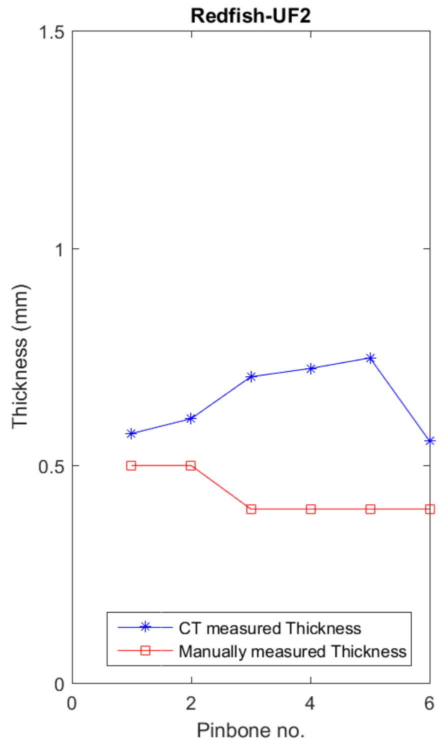

Hake-LYF2
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght

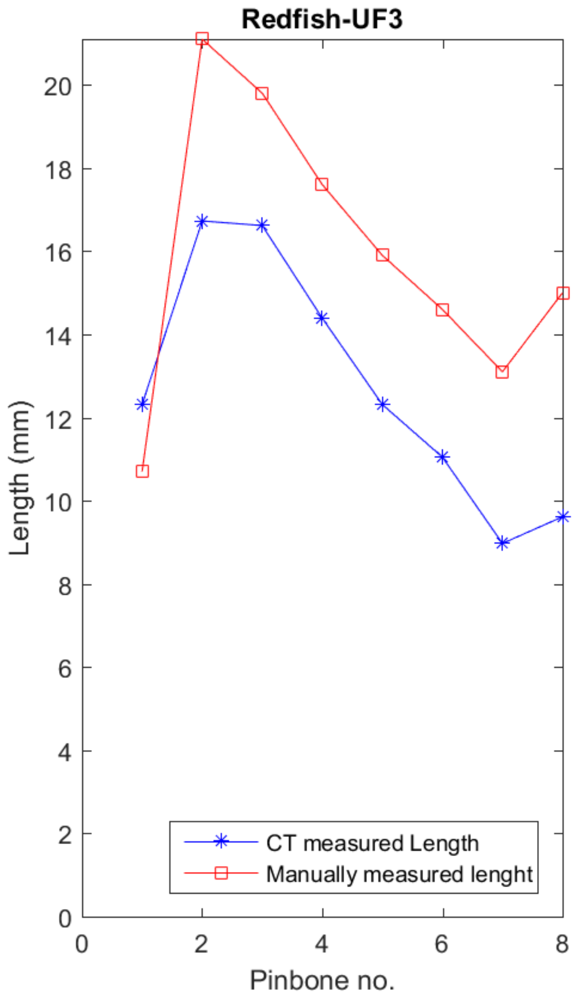

Hake-LYF2
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

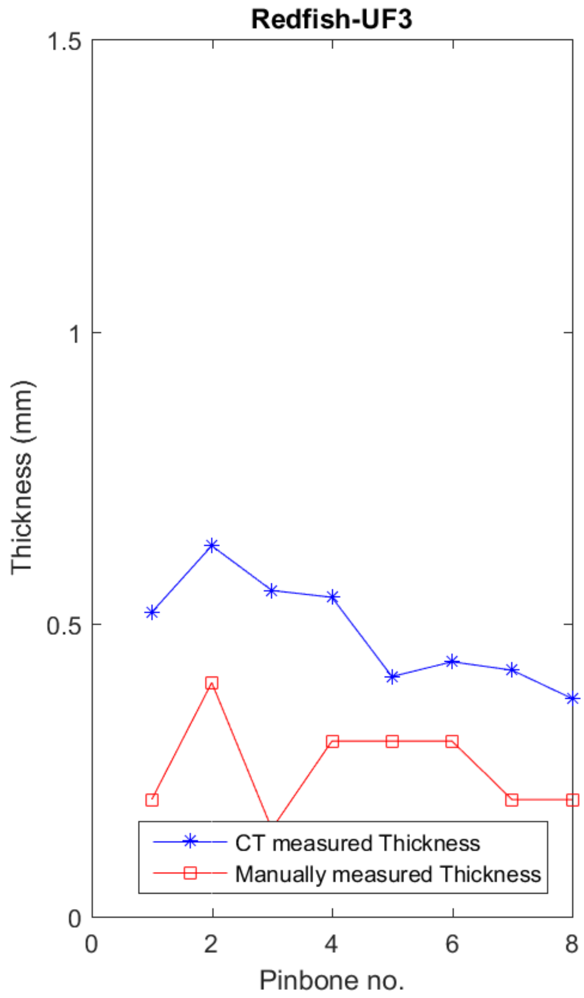

Redfish-UF1
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght

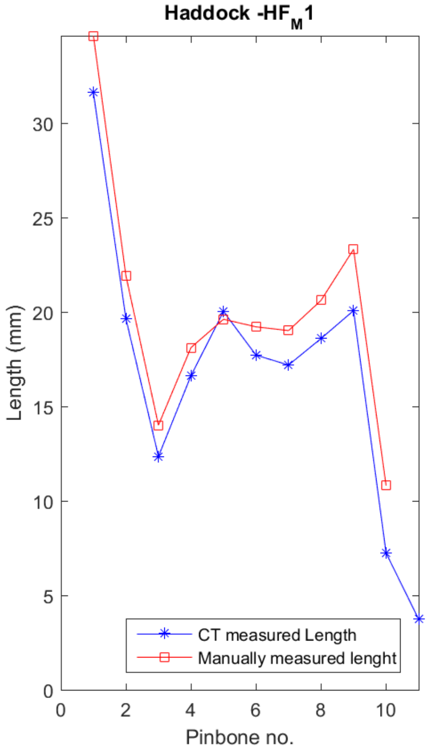

Redfish-UF1
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

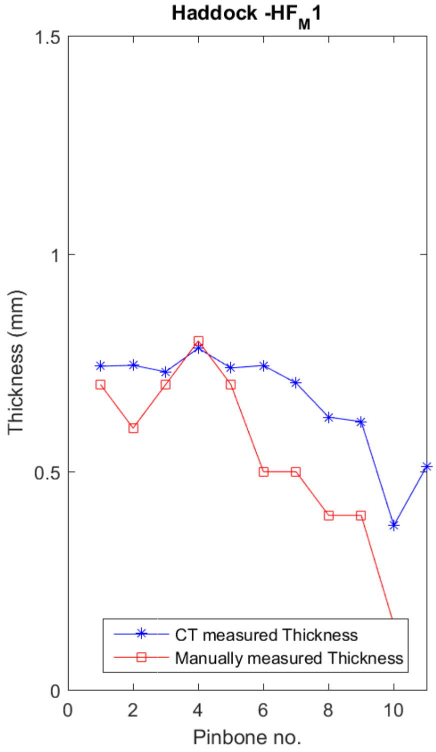

Redfish-UF2
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght

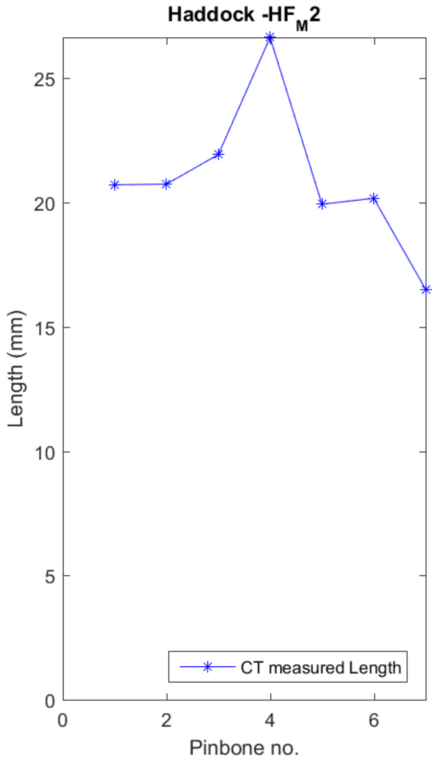

Redfish-UF2
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

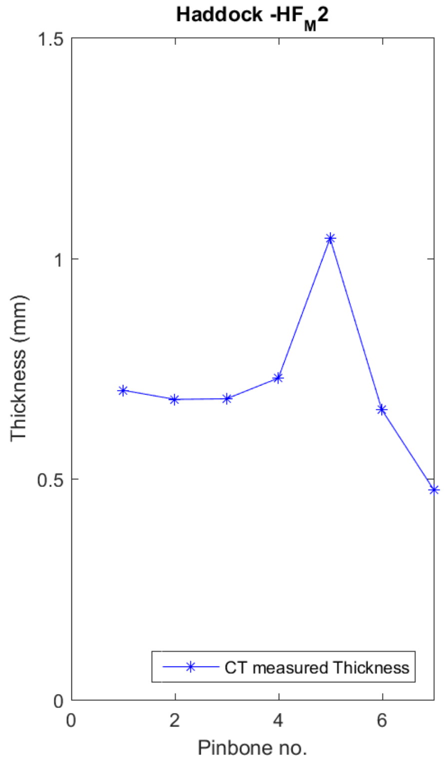

Redfish-UF3
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght
0
2
4
6
8
10
12
14
16
18
20

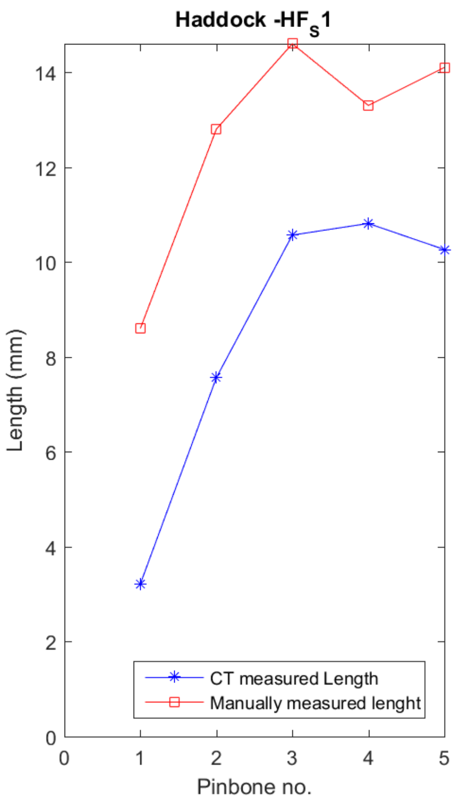

Redfish-UF3
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness
0
0.5
1
1.5

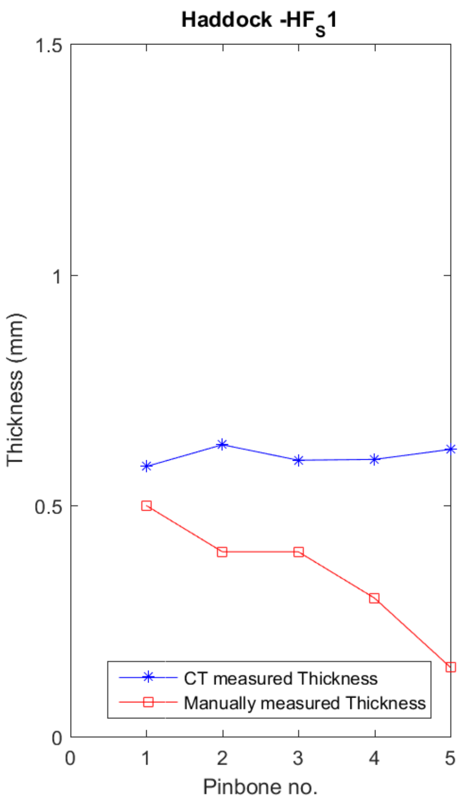

Haddock -HF_M1
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght

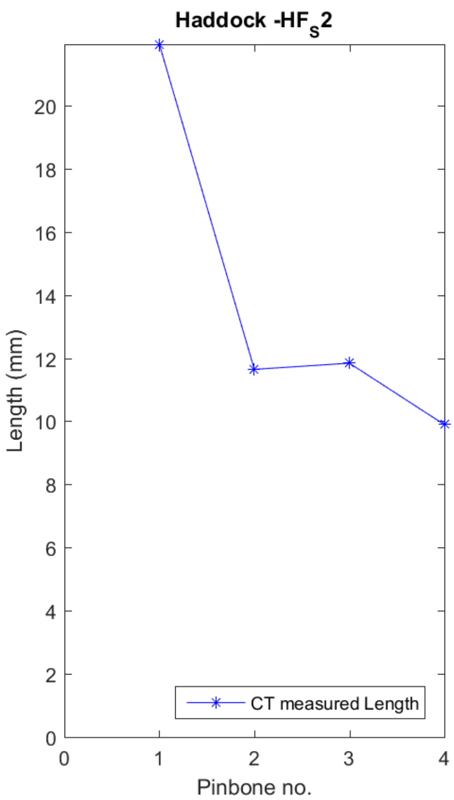

Haddock -HF_M1
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

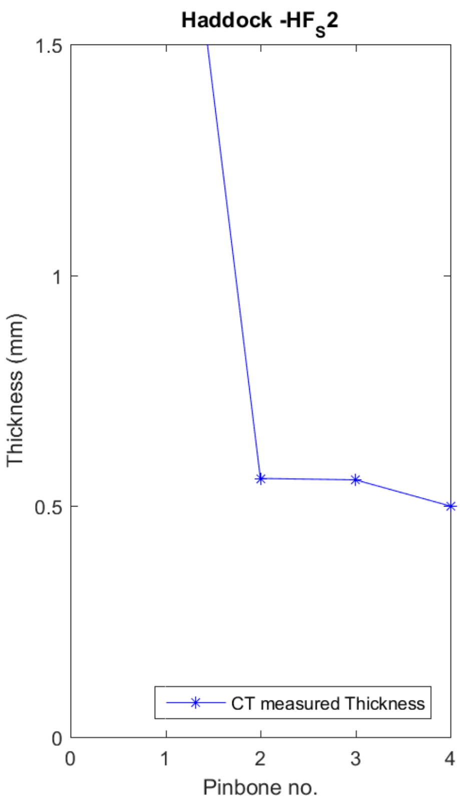

Haddock -HF_M2
Length (mm)
Pinbone no.
CT measured Length

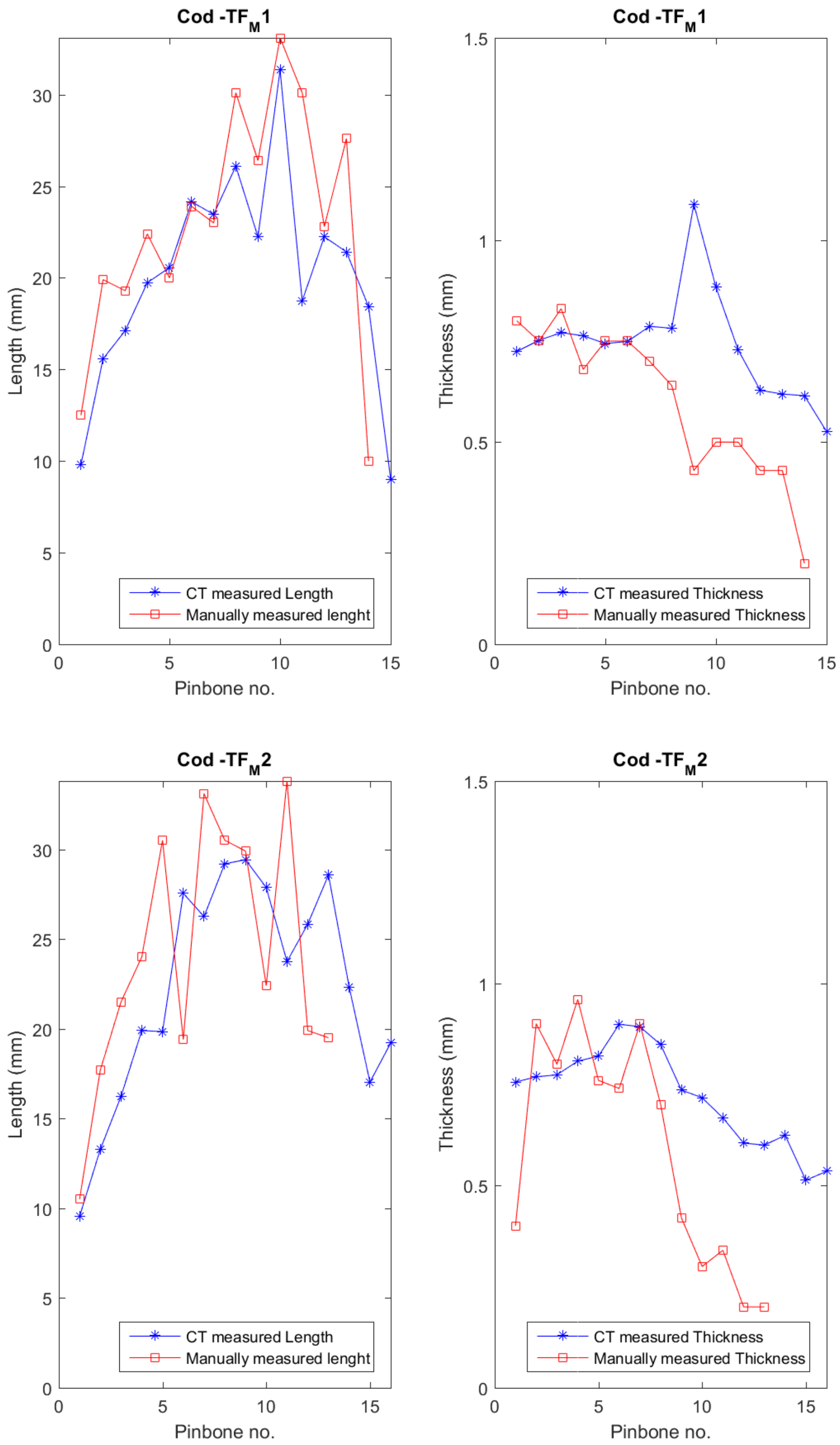

Haddock -HF_M2
Thickness (mm)
Pinbone no.
CT measured Thickness

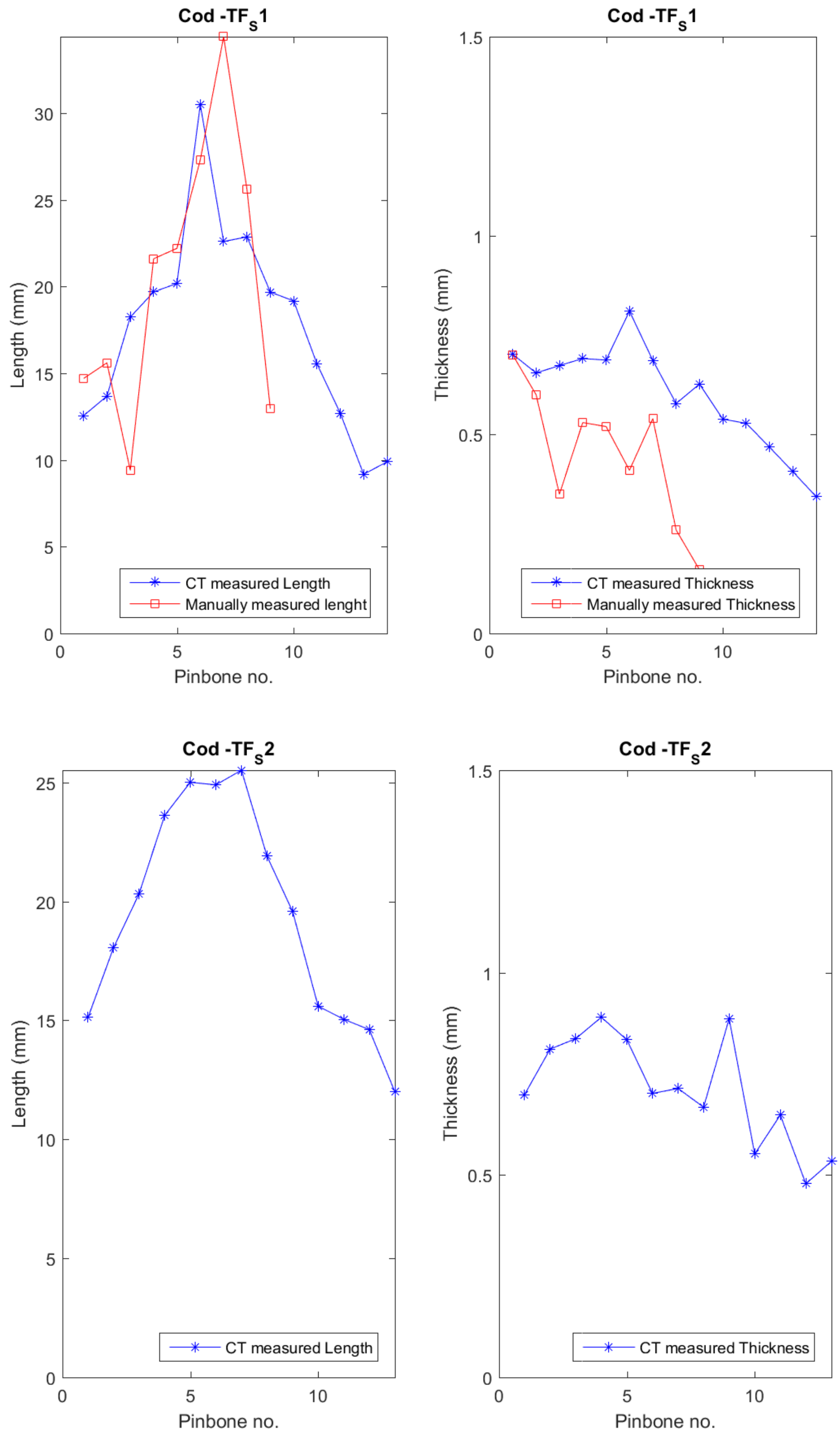

Haddock -HFs1
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght


Haddock -HFs1
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness

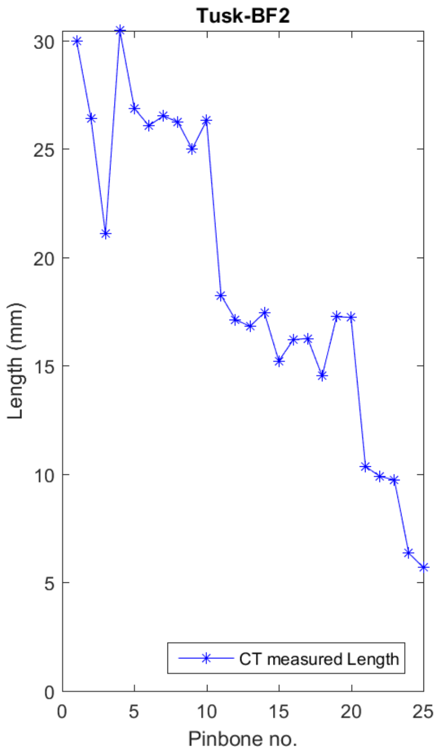

Haddock -HFs2
Length (mm)
Pinbone no.
CT measured Length


Haddock -HFs2
Thickness (mm)
Pinbone no.
CT measured Thickness

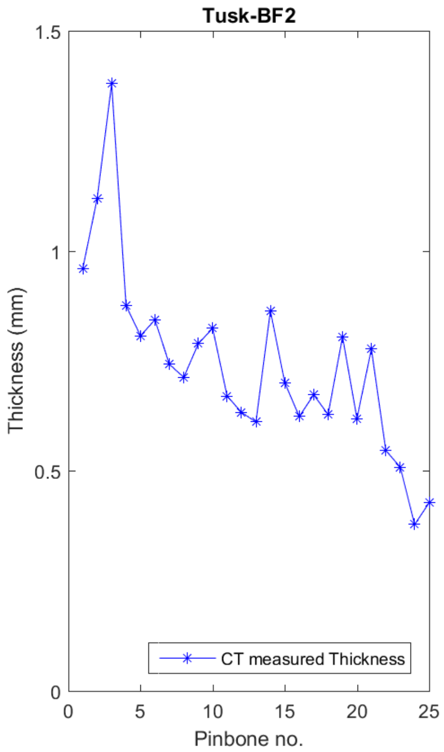

Cod -TF$_M$1
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght
Cod -TF$_M$1
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness
Cod -TF$_M$2
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght
Cod -TF$_M$2
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness



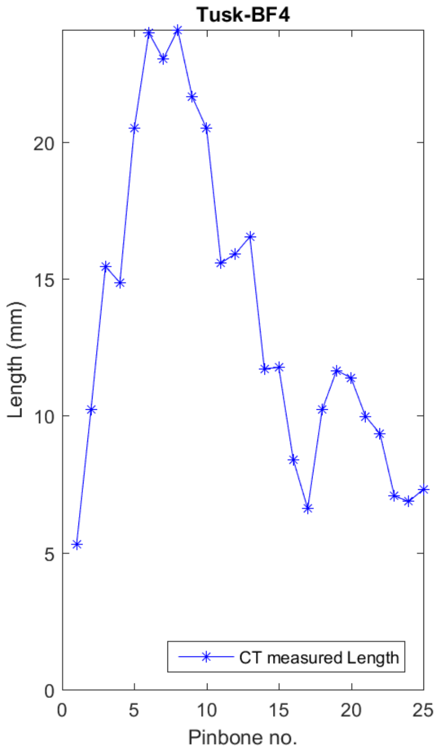
Cod -TFS1
Length (mm)
Pinbone no.
CT measured Length
Manually measured lenght
Cod -TFS1
Thickness (mm)
Pinbone no.
CT measured Thickness
Manually measured Thickness
Cod -TFS2
Length (mm)
Pinbone no.
CT measured Length
Cod -TFS2
Thickness (mm)
Pinbone no.
CT measured Thickness



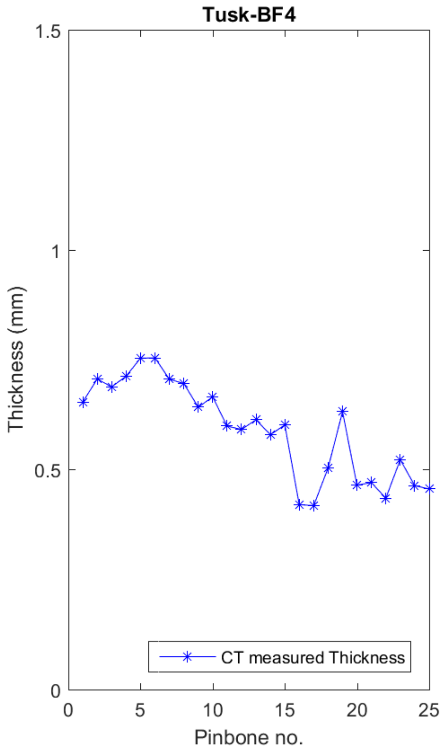
Tusk-BF2
Length (mm)
Pinbone no.
CT measured Length



Tusk-BF2
Thickness (mm)
Pinbone no.
CT measured Thickness



Tusk-BF4
Length (mm)
Pinbone no.
CT measured Length



Tusk-BF4
Thickness (mm)
Pinbone no.
CT measured Thickness

B 3D fish and fillet renderings

In the following pages, we present a 3D rendering of all the fish captured, with the 3D bones plotted in. These illustrations can also be found in the PDF 3D_fish.pdf and 3D_fillets.pdf on the eRoom.

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