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Experimental study of installation procedure and volume estimation of tarpaulin for chemical treatment of fish in floating cages

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A B S T R A C T

In the salmon industry chemical delousing is done by enclosing the cage in a tarpaulin, and then mixing the chemical agent in the enclosed water volume. Correct dosage is important to obtain the wanted effect, and in order to calculate the correct dose of the agent the volume of the enclosed water is estimated based on the geometry of the tarpaulin. The accuracy of this volume estimation is investigated by model experiments in a flume tank. Different tarpaulin shapes, installation procedures and current velocities were examined, and in addition to measuring the volume of the enclosed water, the drag force on the cage/tarpaulin was also measured. The accuracy of the volume estimation was found to be quite low (Root-mean-square (RMS) value of the deviation between estimated and measured volume for all runs was 21%). Certain combination of tarpaulin shape and installation procedure showed less deviation between estimated and volume, and it was found that increased current velocity was favourable with respect to this accuracy.

1. Introduction

Infestation of salmon lice (*Lepeophtheirus salmonis*) is, together with escape (Naylor et al., 2005), currently the main challenge the salmon aquaculture industry in Norway is facing with respect to being environmentally sustainable. Salmon lice are a serious fish welfare problem, and are the most damaging parasite to the salmon farming industry in Norway (Costello, 2006). The consequences for the fish include damaged skin and compromised immunity (Skugor et al., 2008), and in some cases ultimately death (Finstad et al., 2000).

Salmon lice tend to multiply in fish farms because of the density of salmon individuals, and this also increases the infestation on surrounding wild fish (Bjørn et al., 2010). Along with the ecological impact the salmon lice negatively affect the industry's public reputation. With respect to economy, salmon lice infestations involve large expenses for the salmon farmers, approximately 3 BNOK for the total production in Norway in 2014 (Iversen et al., 2015)

The regulations in Norway demand delousing of cages when the average lice density is higher than 0.5 lice pr. fish. Delousing is done by positioning a tarpaulin around the cage on the outside of the net, creating a closed volume, and then mixing delousing chemical agent into the volume. After about 30 min, the delousing is complete and the tarpaulin is removed. There exist several different pharmaceutical products that are used for delousing such as *Alpha Max*, *Betamax*, *Salmosan*, *Trident vet.*, and *hydrogen peroxide*. Common for them all is the importance of having the correct mix of water and agent. Too high concentration is bad for the fish, and too low concentration does not provide the wanted effect. Since the treatment is time consuming, expensive and represent an unwanted chemical discharge it is important to be able to get the correct mix as accurately as possible every time delousing is conducted. In order to get the correct mix it is necessary to know the volume of the enclosed water, and this is the key problem. It is practically impossible to measure this volume, and the only way to get an estimate of the volume is from the size and geometry of the tarpaulin used to create the closed volume. The resulting volume is however not only dependent on the tarpaulin geometry, but also dependent on the ambient current and the procedure used to place the tarpaulin around the cage. This causes uncertainties in the volume estimates, since different farms have different routines.

The main way to install the tarpaulin is however as follows: Before installation the cage bottom is usually raised to a depth of about 3–5 m, so that the fish is concentrated in a smaller volume close to the surface. This is done to minimize the necessary amount of delousing agent, and make the positioning of the tarpaulin easier. The installation is done using a workboat with crane, and initially the tarpaulin is placed on the workboat on one side of the cage, usually on the downstream side, but some farmers, for practical reasons, also start from the side of the cage relative to the current direction. Next, ropes attached on multiple points

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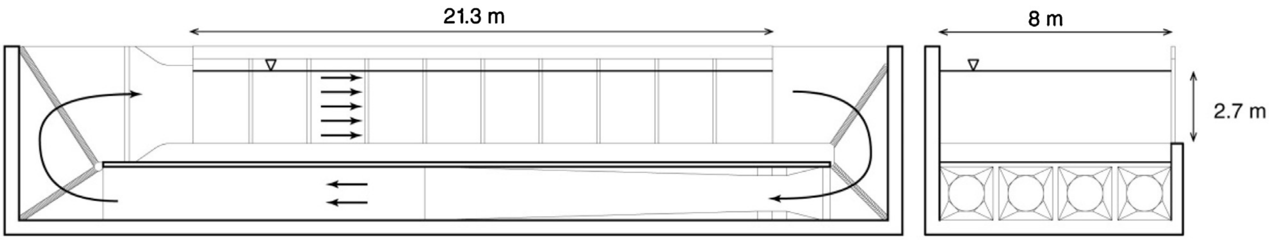

Fig. 1. The North Sea Centre Flume Tank in Hirtshals, Denmark, with an experimental section measuring 21.3 m long, 2.7 m deep and 8 m wide.

around the tarpaulin rim are being positioned at the corresponding positions at the floater rim. Usually there are eight ropes, but some tarpaulins may have a larger number. The tarpaulin is then lowered from the boat while the rope on the opposite side of the cage is being used to drag the tarpaulin under the cage. The ambient water current now helps to fill the volume, and the downstream side of the tarpaulin rim is fixed to the floater rim. Gradually the other ropes are pulled and the tarpaulin rim is eventually fixed all around the floater rim. The sequence of which the ropes were pulled varies between the different farms, and this variation is a part of this study.

One additional problem is that the transformation from an open net based cage to a closed water volume represents a significant change in the behaviour of the cage: suddenly the cage has become a large volume floating structure, in addition to being flexible and compliant. Neglecting to take this behavioural change into consideration when delousing can be dangerous. However, there are few examples where closed flexible membranes/bags/cages are used as ocean structures, and these types of structures are not well understood. The structure that mostly resembles a closed flexible fish cage is the "water bag", of which the first reported application was the *Dracone barge* (Hawthorne, 1961). This is a concept for transporting or storing large quantities of fresh water or other liquid lighter than the surrounding water. Such water bags have been subjected to both numerical and experimental studies of the behaviour in waves and current (Zhao and Aarsnes, 1998; Zhao and Triantafyllou, 1994; Das and Cheung, 2009; Phadke and Cheung, 2003). The closed flexible cage adds, however, to the complexity by having an internal volume of water that has a free surface and an internal flow that is of significant importance to the whole problem. A closed bag will experience a different hydrodynamic drag and deformation compared to an open net based structure. Similar to a flexible net based cage, the flexibility and deformation of the bag is closely coupled to the hydrodynamic forces, making the hydrodynamic load more complex than for a rigid structure. Net based gravity cages are also very compliant and it is well known that when a net deflects from waves and current, attachment and mooring loads can actually be reduced. The deformation characteristics of a closed bag will however be dependent upon the internal water level, more specifically; if the bag is inflated or not. This is highly relevant for the delousing tarpaulin since it during installation may experience both an inflated and a deflated state. A deflated bag will experience significantly more drag in current than an inflated bag (Lader et al., 2014), making a deflated state a potential risk. In waves however, a deflated bag may have a more favourable and safer behaviour than an inflated bag (Lader et al., 2015b). This added complexity when the water volume is closed is important to take into consideration during the delousing procedure.

These uncertainties in estimating the volume of the cage together with the change in behaviour has prompted the necessity to study the different procedures used when installing the delousing tarpaulin. In this work the procedures have been replicated in a flume tank under different current conditions using a scaled (1:17) model of a cage and different tarpaulin geometries. The procedure was filmed for later analysis, and the resulting volume was measured together with the drag load on the cages.

2. Experimental setup

2.1. Flume tank

The experiments were conducted in June 2014 at the North Sea Centre Flume Tank in Hirtshals, Denmark. The tank is a vertical circular water channel, driven by four impellers. The experimental section in the tank is 21.3 m long, 2.7 m deep and 8 m wide, and the maximum water speed capacity is 1 m/s (Fig. 1).

2.2. Test cage

The experiments involve installing a delousing bag around a fish cage, of which there exists many different designs. In these tests however, a Polarcircle type cage with a cylindrical shaped net (conical bottom) and a sinker tube was chosen to be used in the experiments since this is the most used type of fish cage in Norwegian waters. A common size of such cages in Norway is 160 m in circumference of the floating collar (approximately 50 m in diameter), with a depth of approximately 10 m down to the sinker tube. The floating collar is made up of two or three HDPE pipes with a commonly used diameter of 50–60 cm. From the collar the net cage extends as a cylinder down in the water column, and the net is spanned out with a weight system consisting of usually a sinker tube.

A 1:17 scale model of such a cage was used in these tests. The model was 293.3 cm in diameter, and the cage was 58 cm deep down to the sinker tube. The depth of the sinker tube was during the installation of the tarpaulin reduced to 29 cm (corresponding to 5 m depth in full scale) as commonly done during this operation. The model is shown in Fig. 2.

Fig. 2. The model of the Polarcircle type cage with the sinker tube in position for delousing.

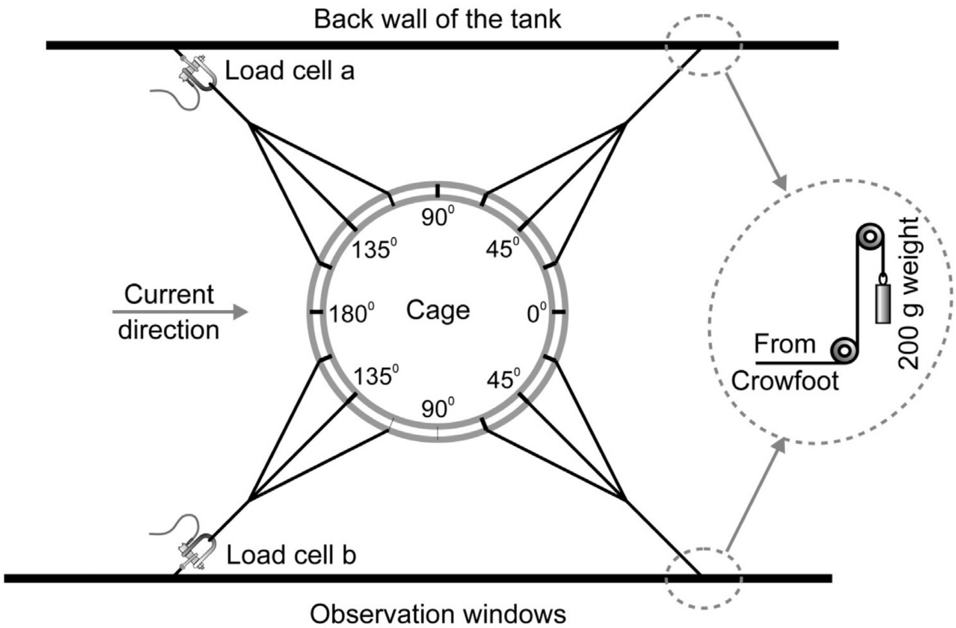

Fig. 3. Mooring arrangements and position of the model in the flumetank.

The test cage was placed in a crowfoot mooring configuration in the tank as shown in Fig. 3. At the downstream side the mooring ropes were pre-tensioned with 1.96 N weight. At the upstream side the mooring ropes were attached to load cells for measurements of the forces on the cage after tarpaulin installation. The load cells used in the experiments were two Futek LSB210 submersible S-beam junior with a capacity of 490 N with an accuracy of ± 1% of total range. The data were recorded on MDA Spider8 with a sampling rate of 10 Hz measured over 90 s, and stored on a computer. The total drag force was calculated as the sum of the force components in the current direction from each of the two load cell.

2.3. Bag models

Four different tarpaulin shapes (bags) were investigated: flat-, conical-, conical section- and spherical shaped tarpaulin (Fig. 4). All the shapes were equipped with a so-called *reduction band* that runs around the circumference of the bag a distance underneath the rim (indicated by the dashed line in Fig. 4). The reduction band is used in an operation called *volume reduction* (VR) which is a technique that is supposed to increase the accuracy of the volume estimation. The idea behind the VR technique is to reduce the volume of the bag once the rim is fixed to the floater. At this stage (with the rim fixed to the floater), the bag usually is deflated, and it is thus difficult to assess the volume. By pulling the bag up and then fixing the reduction band to the floater, the bag eventually inflates, and the idea is that the volume can be estimated with a higher accuracy. During the reduction process the excess captured water is let out of the tarpaulin at the downstream side of the cage. In the crossings between the reduction band and the radial bands, a sling is mounted with a rope to be able to drag the bag in to reduced position.

The models were sewed of water tight parachute fabric. The size of the different tarpaulin shapes are listed in Table 1.

2.4. Installation procedures of the tarpaulin

There are mainly two different ways to install a tarpaulin: Installing it against the ambient current (Fig. 5), and installing it normal to the

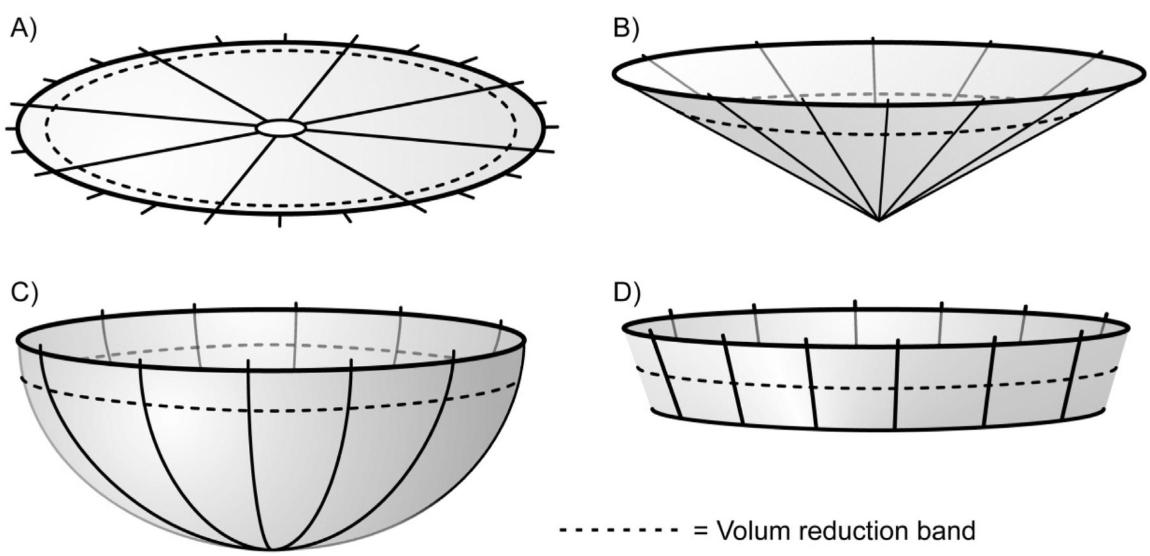

Fig. 4. Tarpaulin shapes (bags) used for the experiments. (A) Flat, (B) conical, (C) spherical and (D) conical section. The conical section model has a flat bottom (not visible in the figure). The dashed lines illustrate the position of the reduction band.

Table 1
The size of the different tarpaulins shapes (bags) in model and full scale. The depth and volume of the conical and spherical shapes was calculated by its geometrical shape, while for the flat and the conical section shapes the tarpaulin will form a sphere when inflated and the volume was for these shapes calculated as a sphere. The spherical and conical tarpaulin shapes were mounted inside the cage while the conical section was mounted outside the cage.

Tarpaulin shape		Model scale (1:17)			Full scale		
		Diameter [cm]	Depth [cm]	Volume [dm^3]	Diameter [m]	Depth [m]	Volume [m^3]
Flat	Volume reduction	359	85.3	3327	61	14.5	16346
		318	51.8	1914	54	8.8	8965
Conical	Volume reduction	318	88.2	2336	54	15.0	11477
		287	80.0	1719	49	13.6	8445
Spherical	Volume reduction	324	76.5	3376	55	13.0	16586
		287	58.5	2039	49	9.9	10018
Conical section	Volume reduction	324	80.0	3950	55	13.6	19406
		289	59.4	2602	49	10.1	12955

current (Fig. 6). To help installation the tarpaulin is equipped with ropes in eight positions along its rim: 0°, ±45°, ±90°, ±135° and 180°. These ropes are at least long enough to run from one side of the floater to the other. Before installation begun, the tarpaulin was positioned at the indicated deploy position, and the ropes where run from the deployment position and to the corresponding position on the floater. In a

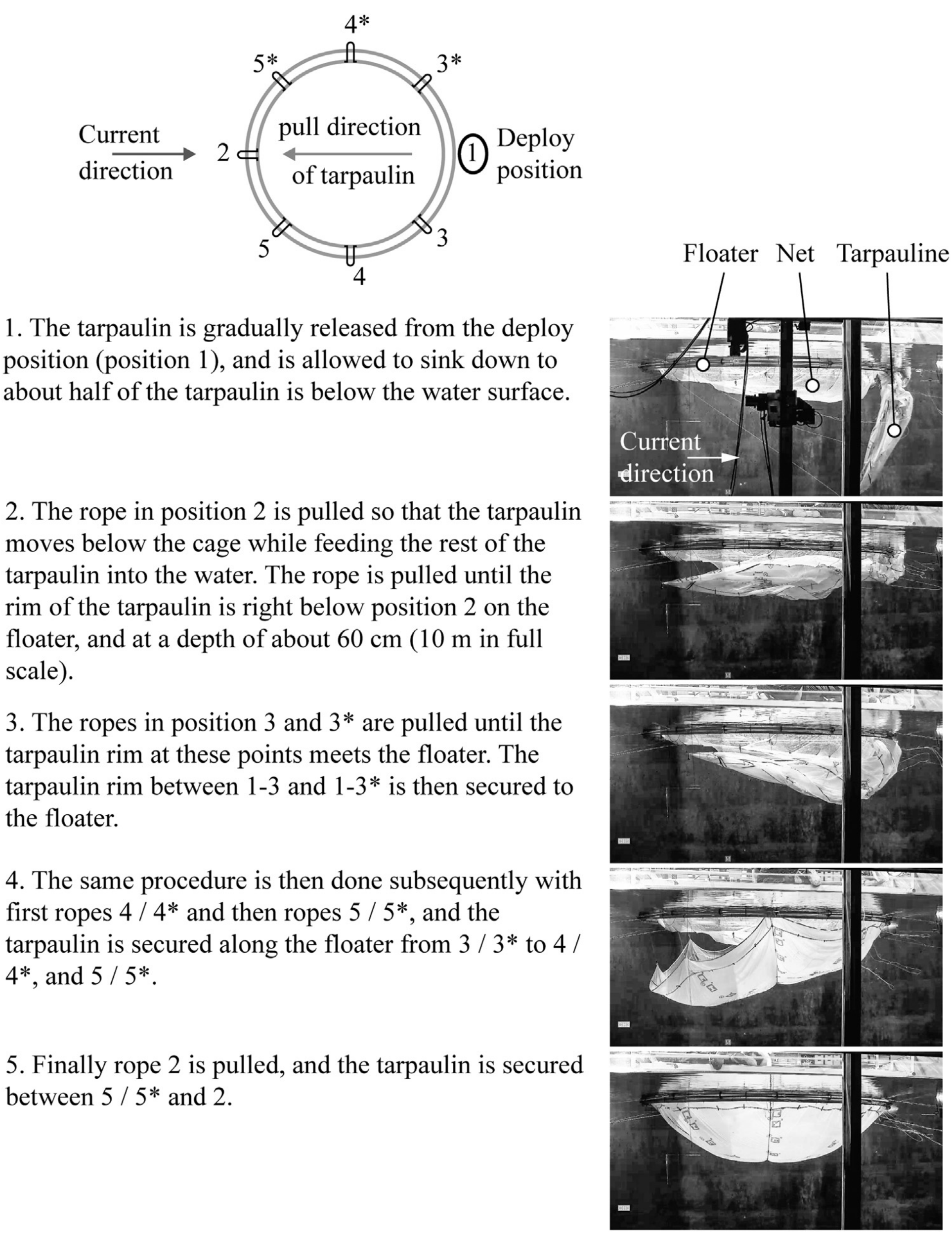

Fig. 5. Installation procedure (A) Installing it against the current.

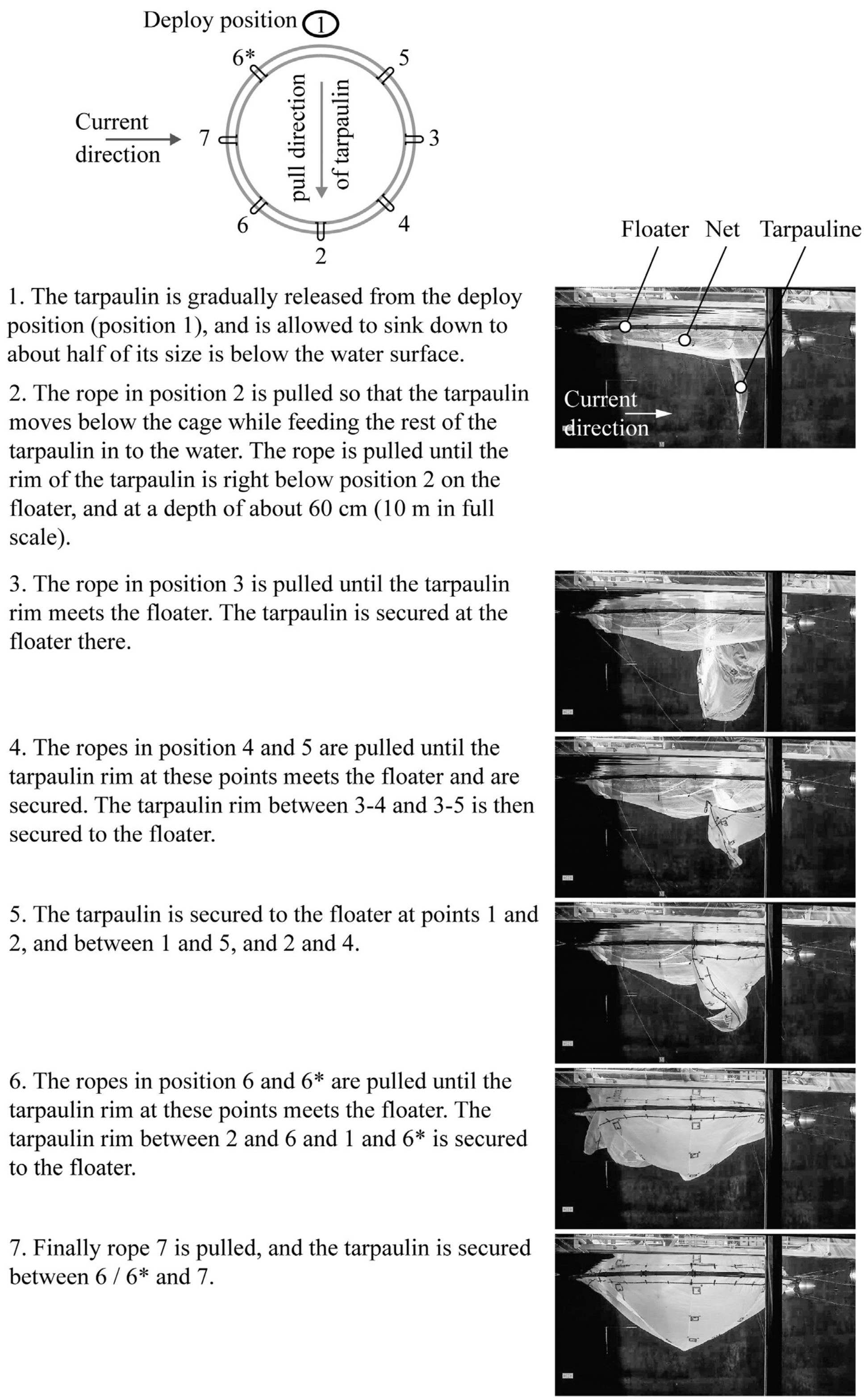

Fig. 6. Installation procedure (B) Installing it normal to the current.

real situation the tarpaulin is initially positioned in a workboat, and the ropes are positioned by walking the end along the floater to the correct position.

In order to get the tarpaulin down and around the cage it is necessary to use weights for the tarpaulin to sink, since the tarpaulin itself is more or less naturally buoyant. One to three weights are normally used, and the size and position of these weights are given in Table 2.

In some cases the volume is reduced by using the reduction band after the tarpaulin is secured to the floater. The ropes at the reduction band are then pulled until the reduction band surfaced and is secured to the floater. The volume of the water inside the tarpaulin was measured after each run by pumping out the water through a flow measurement device.

In order to get representative results it is important that the deployment routine done in the laboratory resembles the deployment routine in full scale. Since the routine is rather complex and involves

Table 2
Weights used on the tarpaulins at different positions dependent on the installation procedure. The weight size and positions are similar to the routines used by industry in Norway.

Tarpauline shape		Against the current			Normal to the current		
		Position 5	Position 2	Position 5*	Position 2	Position 7	Position 3
Flat	Model scale [g]		138		138	78	
	Full scale [kg]		678		678	383	
Conical	Model scale [g]	25	60	25	60	25	25
	Full scale [kg]	123	295	123	295	123	123
Spherical	Model scale [g]		218		60	25	
	Full scale [kg]		107		295	123	
Conical section	Model scale [g]		138		138	78	
	Full scale [kg]		678		678	383	

multiple steps the only way to do it in the laboratory was to have one of the research team perform the routine manually with the inherited natural variation one must assume in all human activity. The procedure is sought to mimic the real full scale procedure, and the variance in the installation is postulated to be of the same magnitude as one can experience in real full scale installations. It is practically impossible to assess the validity of this postulate, and it is therefore important to keep this potential uncertainty in mind when the results are analysed. The speed of deployment and installation in model scale was ~7–9 min, corresponding to 30–37 min in full scale.

2.5. Current velocities

A total of 122 runs were carried out with different tarpaulin shape, installation procedures and current velocities. The installation procedure tested at the following current speeds: 0, 2, 5, and 10 cm/s (corresponding to approximately 0, 8, 21, and 41 cm/s in full scale). These current velocities are relevant with respect to the sites used for salmon farming in Norway. There may, for unforeseeable reasons, arise situations during delousing where the current velocity increases above the limiting velocity. This could become a potential dangerous situation, and it is relevant to study how the installed tarpaulin behaves at higher current velocities, with emphasis on the resulting drag force. Some combinations were therefore exposed to higher velocities: 13, 15, 17, 18 and 20 cm/s (corresponding to approximately 54, 62, 70, 74 and 83 cm/s in full scale).

3. Results and discussion

The results of the volume measurements of installed tarpaulin are shown in Table 3. The volume of the bag can be estimated using the main dimensions, and this is given as *estimated volume* (as also given in Table 1). This represents the estimate a farmer will use to calculate the mix of water and chemical agent, and an error in this estimate will directly influence the concentration of the agent in the bag. For each combination of current/tarpaulin shape/installation procedure that was tested the measured volume of the enclosed water is given. Together with the measured volume, the relative deviation is also given. This deviation is calculated as: Relative deviation [%] = (measured volume [dm^3] − estimated volume [dm^3])/estimated volume [dm^3]. In several of the combinations multiple runs were done to assess for repeatability and accuracy. In those cases the numbers of multiple runs are given in brackets, and the measured volume is taken as the average of all runs. The relative standard deviations for the repeated runs varied between 1 and 32%, with an average of 10%. This variation is not caused by uncertainty in the measurements methods, but is due to the variance in the installation procedure from run to run due to the manual way it is performed. The variation in the installation procedure have two components. First it is the difference in how the ropes are pulled from run to run. This is mainly due to variations over time in the velocity the ropes are pulled and in the exact positions the ropes are pulled from. The process is done manually and, even though it was sought to do this similar, there were differences from run to run. The second component is due to the inherently chaotic behaviour a highly flexible tarpaulin will have in current. Small differences in flow may cause large differences in tarpaulin behaviour. In real situations the flow can have temporal and spatial differences which will contribute to a low repeatability of the installation procedure due to this effect. The flow in the flume tank will also have variations due to imperfect current generations and disturbances that will result in a variation in the installation procedure.

RMS (Root Mean Square) values of the volume deviation for certain groups of combinations are also calculated and shown in the table. Since each individual measurement must be assumed to have an inherited variation (standard deviation) of 10% in average it is difficult to make conclusion on individual measurement. The RMS values however are combined of multiple runs and these values can give indications on what overall combinations are favourable.

Looking at the volume results in Table 3 it suggests that there is an overall significant deviation between the estimated volume and the measured volume. The RMS of the relative deviation for all 54 runs is 21%. It is desirable to limit the error in the dosage of the medication to ±2% for hydrogen peroxide, and to ±5% for other chemicals (based on conversations with farmers and medical companies). A deviation of 21% of the volume estimation may thus be potentially critical. However, there are differences between the different tarpaulin shapes and installation procedures, and the results indicate that it is possible to reduce the deviation by choosing an optimal combination. Most notably the conical section tarpaulin show significant lower deviations with a RMS of 9% for all 16 runs with this shape. Experiences from the experiments indicate that this tarpaulin behave significantly differently that the others when it is installed, especially its ability to capture the water which made it easier to get the right filling level with this tarpaulin.

The RMS for different current velocities during installation shows that higher current velocity is favourable. For installation without current the RMS is 26%, while for 41 cm/s full scale current the RMS is 16%. Needless to say, higher current velocities have other effects, like increased drag, and this effect will be discussed later. The installation direction relative to the current does not seem to have any effect at all. Both the installations normal to the current, and against the current show a RMS of 21%, although the installation normal to the current was tested in much less extend (7 runs) than against the current (47 runs), and the test combinations was not overlapping with respect to the different combinations of tarpaulin and current velocity. Further tests are necessary to conclude on this issue.

Table 3
Measurements of the water volume after tarpaulin installation for different tarpaulin shape and combinations of volume reduction (yes/no), installation direction and current velocity. A total of 55 runs were conducted, and for each combination the measured volume in dm^3 is given together with the resulting relative deviation for the estimated volume (gray area). The estimated volume is the volume calculated from the ideal shape of the tarpaulin (as given in Table 1). For some of the combinations repeated runs were done to assess the accuracy, and this is indicated with the number of runs in brackets. For the cases with multiple runs, the volume is taken as an average over all the repeated measurements, and the error is calculated using this average. RMS (Rooth Mean Square) values of the deviations for all the runs in different combinations are also given in the table.

Tarpaulin shape	Installation procedure: Volume reduction	Installation procedure: Installation direction wrt current	Estimated volume [dm^3]	Measured water volume [dm^3] after installation of tarpauline and relative deviation from estimated volume [%]; Current during installation (full scale values in brackets): 0 cm/s	2 cm/s (8.3 cm/s)	5 cm/s (20.6 cm/s)	10 cm/s (41.2 cm/s)	RMS (Combined deviation) Tarpauline shape and installation procedure combinations		
Flat	No	Normal	3327		2040 -39 %		2158 -35 %	37 % (2)	28 % (4)	23 % (9)
		Against				2682 -19 %	3090 -7 %	15 % (2)		
	Yes	Against	1914	2058 8 % (2)	2279 19 %	2301 20 % (2)		19 % (5)		
Conical	No	Normal	2336	1940 -17 % (5)	2334 0 %			0 % (1)	22 % (12)	22 % (16)
		Against			2084 -11 % (3)	2417 3 % (2)	2819 21 %	23 % (11)		
	Yes	Against	1719	1382 -20 %	1943 13 % (2)	2070 20 %		19 % (4)		
Spherical	No	Normal	3376	2231 -34 %	2913 -14 %		3648 8 %	11 % (2)	16 % (6)	29 % (13)
		Against			3616 7 %	3634 8 % (2)		18 % (4)		
	Yes	Against	2039	2738 34 % (3)	2747 35 % (3)	2889 42 %		36 % (7)		
Conical section	No	Normal	3950				3667 -7 % (2)	8 % (2)	8 % (6)	9 % (16)
		Against			3968 0 %	4015 2 % (2)	4193 6 %	8 % (4)		
	Yes	Against	2602	2566 -1 % (3)	2790 7 % (3)	2715 4 % (2)	3667 -7 % (2)	9 % (10)		
RMS (Combined deviation) Current				26 % (15)	21 % (17)	18 % (13)	16 % (9)	**21 % (54)**		

RMS (Combined deviation) Installation procedure combinations			
	Volume reduction	No	20 % (28)
		Yes	22 % (26)
		Normal	21 % (7)
		Against	21 % (47)

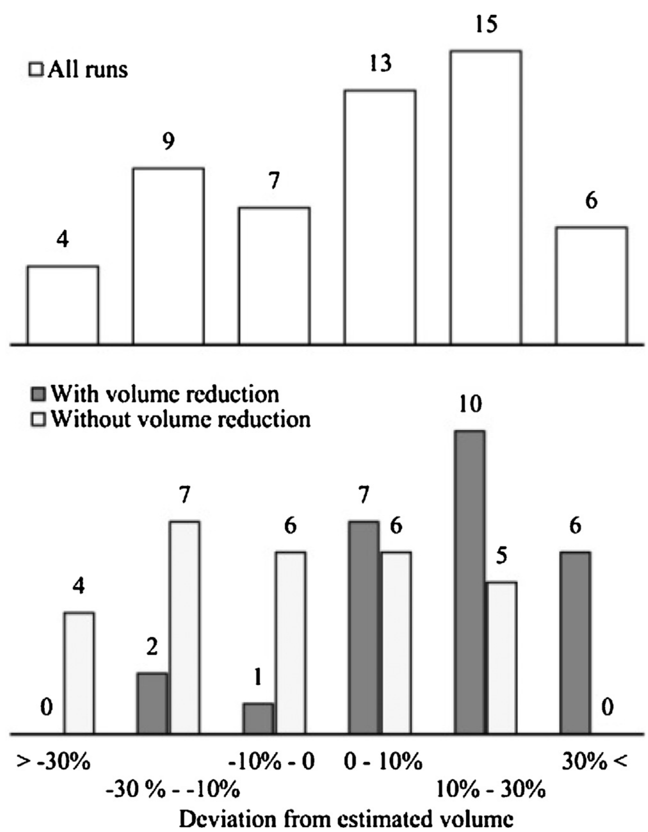

Fig. 7. Distribution of the deviation from estimated volume [%] for all individual runs (top) and also sorted for with and without volume reduction (bottom). Note that the interval spacing is not equal (0–10%, 10%–30% and 30% <).

One method that has been devised by the farmers to increase the accuracy of the volume estimation is the volume reduction (VR) method (described earlier). The results indicate however that this method does not have a significant effect, as RMS of the volume deviation for the runs where VR was used was 22%, while it was 20% for the runs without VR. The results for all the runs with VR show however an interesting trend. While the volume deviations for the runs without VR show an even distribution between over and under estimation, the runs with VR have almost uniquely more water in the tarpaulin than the estimated volume (see Fig. 7). This is naturally due to the nature of the method; first capture the water, then reduce the volume. This indicates that the VR method has potential to work if the reduction is done

Table 4

Measurements of the drag force. The drag force was measured using two load cells, one in each of the upstream mooring lines (Fig. 3). The drag force is the sum of the components in current direction of both these load cells. The contribution from weight used in the downstream moorings is subtracted. For some of the lowest velocities, the drag was measured to be negative (indicated in gray). This is due to random measurements errors and these measurement points are discarded. For some cases multiple runs were done to assess the accuracy. For these cases the resulting drag is the average of all runs, and the relative standard deviation is also given. The measurements are plotted in Fig. 8. The drag of the cage without tarpaulin is also given.

Tarpauline shape	Volume reduction	Model scale		Full scale		Number of repetitions	Relative standars deviation
		Current [cm/s]	Drag [N]	Current [cm/s]	Drag [103kg]		[%]
Flat	No	2	-0.3	8.2	-0.1		
		5	1.0	20.6	0.5		
		10	3.0	41.2	1.5	(2)	73 %
	Yes	2	-0.3	8.2	-0.2		
		5	1.6	20.6	0.8	(2)	7 %
		10	2.0	41.2	1.0		
		13	3.0	53.6	1.5		
		15	5.5	61.8	2.7		
		18	8.6	74.2	4.3		
Conical	No	2	0.9	8.2	0.4	(4)	127 %
		5	1.6	20.6	0.8	(2)	84 %
		10	2.6	41.2	1.3	(2)	24 %
		13	4.0	53.6	2.0	(2)	
		15	6.1	61.8	3.1	(2)	9 %
		17	12.2	70.1	6.1		
		18	17.0	74.2	8.5		
		20	21.3	82.5	10.7		
	Yes	2	2.1	8.2	1.0	(2)	132 %
		5	0.9	20.6	0.5		
Spherical	No	2	0.8	8.2	0.4	(2)	110 %
		5	1.9	20.6	0.9	(2)	7 %
		10	2.7	41.2	1.3		
	Yes	2	0.8	8.2	0.4	(3)	228 %
		5	1.6	20.6	0.8		
Conical section	No	2	0.0	8.2	-0.01		
		5	1.5	20.6	0.7	(2)	25 %
		10	1.9	41.2	1.0	(4)	46 %
		13	3.2	53.6	1.6		
		15	4.7	61.8	2.3		
	Yes	2	0.9	8.2	0.4	(3)	122 %
		5	0.9	20.6	0.5	(2)	12 %
		10	3.1	41.2	1.5	(2)	27 %
Caged only (fully expanded with sinkertube at normal position)		5	2.6	20.6	1.3		
		10	9.9	41.2	5.0		
		15	19.1	61.8	9.6		
		20	28.7	82.5	14.4		

correctly. The tarpaulins obviously capture enough water; it is only a question of reducing the volume to the estimated volume. This should be feasible if the technique is refined.

The drag measurements are shown in Table 4 and Fig. 8. At low current speeds the results from the drag force measurements were unstable and not reliable. This can be seen from the relative standard deviations in Table 4. The load cells with a range of 0–490 N, had a nonlinearity of up to ±1% of rated output which corresponds to an uncertainty of ±4.9 N. The measured forces should thus only be used as indications. One important observation can however be made based on the drag measurements: As the current velocity (full scale) increases beyond 0.4 m/s (the considered limiting velocity for such operations is 0.35 m/s), the drag force increases radically. This means that although higher velocities are favourable with respect to estimating correct volume it is potential dangerous to use this as a strategy, since an increase in current velocity during installation might result in dramatic increase in drag. It has been shown that closed flexible cages in a deflated state have up to 2.5 times larger drag than in an inflated state (Lader et al., 2015a). This is due to the formation of a concave front of the cage as it deforms in current. The installation phase of the delousing tarpaulin resembles this, and a similar increase in drag must be expected.

4. Summary and conclusions

The main conclusion from the presented results is that the accuracy of the volume estimation for the delousing tarpaulin is high (RMS = 21%). This accuracy is significantly lower than what is considered satisfactory (<5%). There are significant differences in the accuracy for different tarpaulin shape and current velocities. The tarpaulin shape with the best accuracy in volume estimation is the conical section (RMS = 9%), at the results also indicate the volume estimation becomes more accurate for increasing velocities. The method of volume reduction (VR) does initially not show to have an effect with respect to the RMS values of the volume deviation. However, when VR is used the water volume is almost always larger than the estimation, as opposed to when VR is not used the volume is equally over- and under-predicted. This indicates that the method of VR have a potential to increase the accuracy of the volume estimation if the method is refined. It is clear that tarpaulins capture enough water, and that the volume of the water before the volume is reduced is larger than the estimated volume for the reduced volume. As the volume is reduced, water has to be let out of the bag, and the key issue is to stop the volume reduction as the bag reaches the estimated volume. If a reliable method for doing this is established, the VR method has the potential to increase the accuracy of the volume estimation.

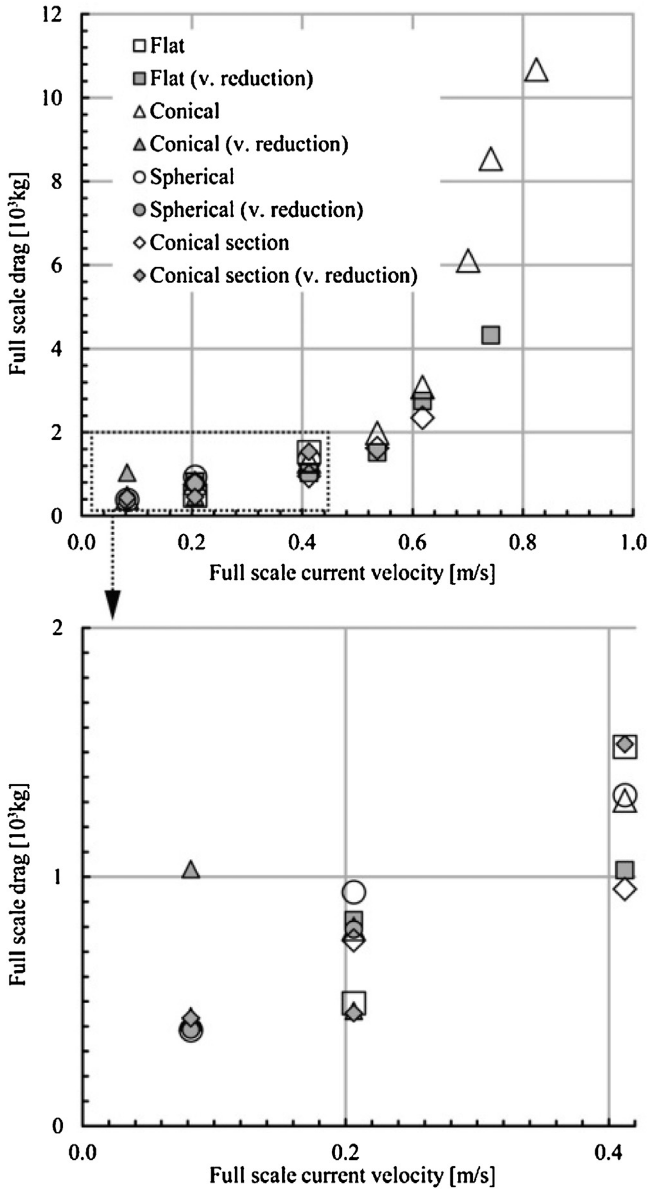

Fig. 8. Drag measurements plotted as a function of current velocity.

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