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Report

Simulating the Effectiveness of Demersal Seine Fishing: Effect of Seine Rope Layout Pattern and Haul-in Procedure

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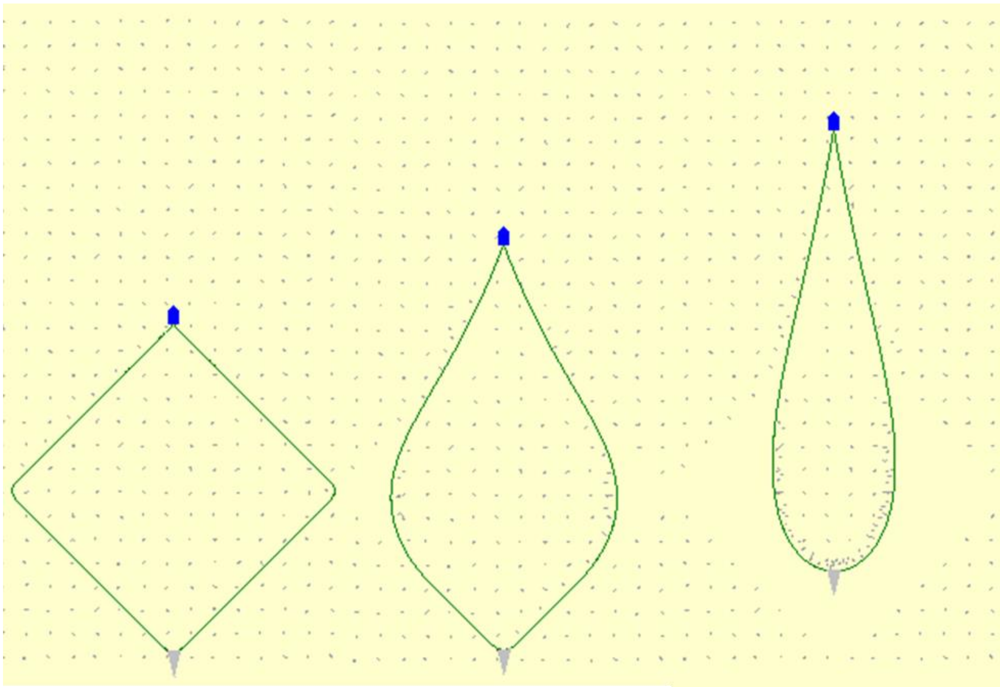

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ABSTRACT
Demersal Seining is an active fishing method applying two long seine ropes and a seine net. The effectiveness of demersal seining relies on that fish near the seabed reacts to the seine rope moving on the seabed during the fishing process. The seine ropes and net are deployed in a specific pattern encircling an area on the seabed. In some variants of demersal seining the haul-in procedure includes a towing phase where the fishing vessel moves forward before starting winching in the seine ropes. During the haul-in process the shape and size of the seine rope encircled area gradually change. The main purpose of the seine rope movements during this phase is to concentrate the fish population at the seabed in an area where they later are overtaken by the seine net. The initial seine rope encircled area, the gradual change in it during the haul-in process and the fish reaction to the moving seine ropes therefore play an important role in the catching performance of demersal seine fishing. The purpose of the project "Danish Seine: Computer based Development and Operation" (MAROFF-2 project no. 225193 / FHF 900861), funded by Research Council of Norway (RCN) and Norwegian Seafood Research Fund (FHF), is to develop software tools to investigate Demersal Seine fishing. This specific report from the project investigates the catching performance of demersal seine fishing by using simulation models developed in the project.

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1 Introduction

1.1 Background and Objectives

The purpose of the project *Danish Seine: Computer based Development and Operation* (MAROFF-2 project no. 225193 / FHF project no. 900861), funded by Research Council of Norway (RCN) and Norwegian Seafood Research Fund (FHF), is to develop software tools to investigate demersal seine fishing. These tools include a model for simulating the physical behaviour of the seine ropes during the fishing process and a model for how fish reacts to an approaching seine rope during the fishing process. The specific purpose of this report is to apply those models to investigate the catching performance of demersal seine fishing. Specifically how initial seine rope layout pattern and the haul-in procedure affect the catch performance.

1.2 The Demersal Seine Fishing Process

The Danish seining or anchor seining is an active demersal fishing technique which was invented in Denmark and in the first half of the 20th century became one of the most important fishing gears used there [1]. When this fishing method was brought to other countries, it was modified to local conditions and customs. Scottish fishermen started to fish without anchoring, making it possible to move the vessel forward during hauling and thereby including a towing phase. This technique is known as Scottish seining, 'Fly-dragging' or 'Fly-shooting', and is also the method primarily applied by Norwegian fishermen targeting cod and haddock [2]. Together these variants of this fishing method can be termed as demersal seining. Today its importance as a commercial fishing method in Denmark and other parts of the world is increasing due to its low fuel consumption, high catch quality and low ecosystem impacts when compared to trawling [3-6]. For example about 20% of the Norwegian cod quota is caught by demersal seining; the Norwegian style fly dragging [7]. Thus, knowledge about the physical behaviour of this type of fishing gear and its ability to collect fish for the seine net is very relevant. It is relevant to investigate how effective the different variants of the demersal seining is compared to each other in particular the effect on catch performance of layout pattern deployed and by the inclusion of a towing phase and its duration. Demersal seining in Norwegian fishery targeting cod and other demersal species is practiced by deploying two long seine ropes connected to the wing tips of the seine net in one end and the winches of the vessel on the other end. The length of the seine ropes is restricted to 2000 m each when fishing inside the four nautical mile limit. The seine ropes, made of up to Ø60 mm combination rope (polyethylene with a steel core) weighing more than 2 kg/m, are placed on the seabed often in a quadrilateral pattern in order to encircle the targeted fish [8]. Once the ropes and the net have reached the seabed the vessel starts moving forward at a speed of 1-2 knots. As a result of the vessel movement the seine ropes are moving towards each other and herd the fish into the centre of the encircled area; the collecting phase. At some instance the net will start to move along the seabed being pulled by the seine ropes. When the distance between the ropes has decreased to a certain level the rope drums are activated in order to close the wings fast and to force the last fraction of collected fish into the seine net; the closing phase. This fly dragging principle of demersal seining is shown in Figure 1.

The catching performance of demersal seine fishing depends on the area on the seabed swept and encircled by the seine ropes during the fishing process and by the efficiency of the seine ropes are able to herd the fish into and subsequently maintain them in the path of the much smaller seine net until they are overtaken by it in the later stages of the fishing process. Knowledge about how the size and shape of the area encircled by the seine ropes gradually change during the fishing process and how it gradually leads increased density of fish in it is therefore important for an efficient fishery. Thus, understanding and quantifying the physical behaviour of the seine ropes and how this behaviour gradually leads to increased density of fish in the encircled area are important aspects of the demersal seine fishing process. This subject is investigated by applying a simulation model for demersal seine fishing that predicts the amount of fish being collected between the seine ropes during the fishing process. The simulation model consists of combining a model for the physical behaviour of seine ropes with a simple model for fish reaction to an approaching seine rope at the seabed. Results are provided for a Norwegian demersal seine fishery targeting cod (*Gadus morhua*) in the coastal zone.

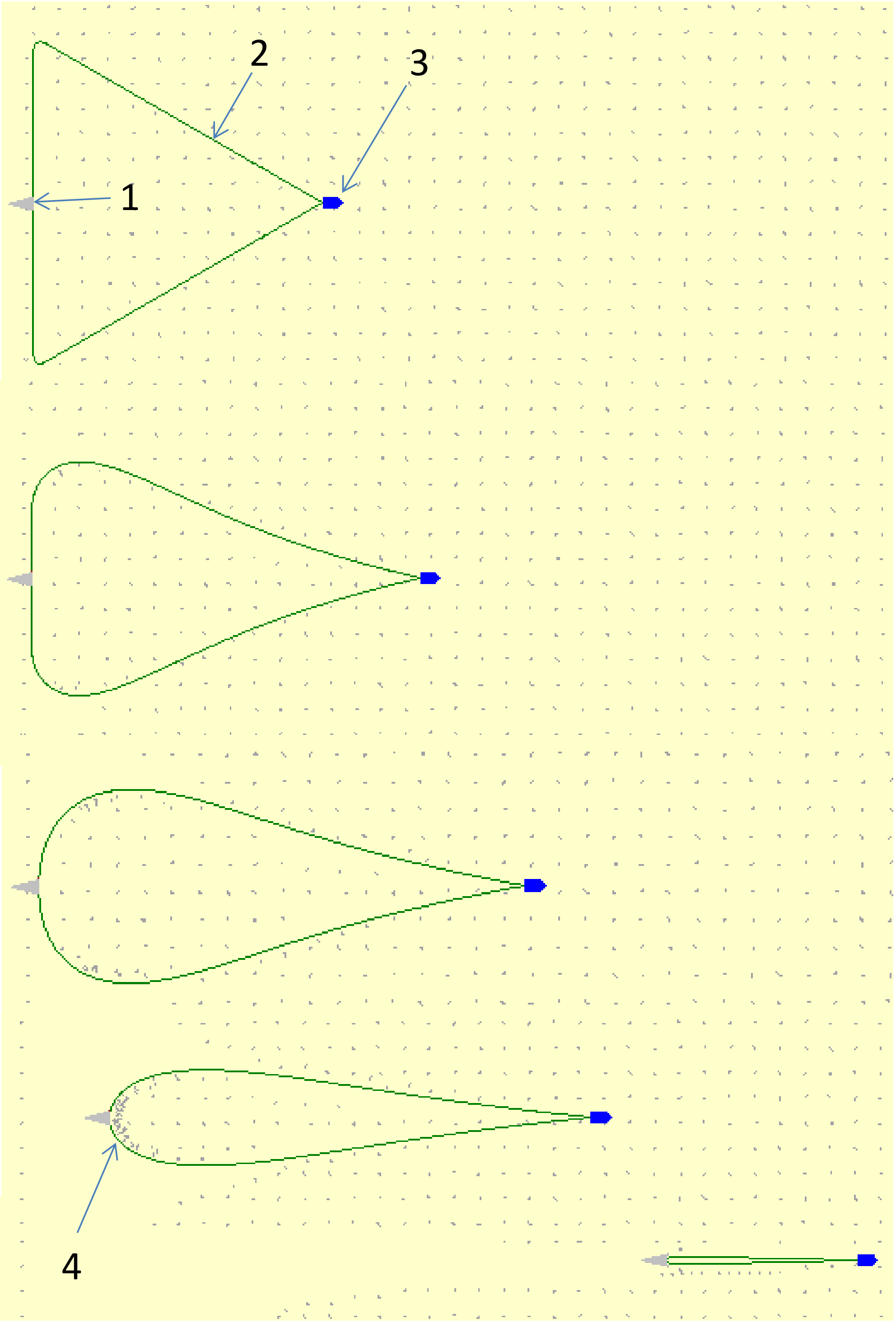

Figure 1: Demersal seine fishing procedure (collection and closing phase) from top to bottom. 1: seine net. 2: seine rope. 3: fishing vessel. 4: fish collected ahead of seine net. The grey dots represent aggregations of fish at the seabed. In this case the fish is being uniformly distributed. Seine net, fishing vessel and fish aggregations are scaled up compared to the length of the seine ropes for illustration purposes.

2 Models and Methods

2.1 Method for Simulation of Seine Rope Behaviour

The dynamics of the demersal seine fishing gear is dominated by the behaviour of the seine ropes. Hence, we needed for the investigations a tool that can predict the physical behaviour of the seine ropes during a demersal fishing process. We applied an existing tool hereafter named *SeineSolver*. *SeineSolver* has an interface that enables the user to specify the gear deployed including the characteristic of the seine ropes and the fishing operation in terms of layout pattern for the seine ropes, towing speed, towing time before starting winching and winching speed. *SeineSolver* uses the *FhSim* simulation framework [9]. The seine ropes were modelled by cables consisting of a collection of six degree of freedom elements. The cables were connected to the weight at one end, representing the seine net, and to a winch at the other. Since the demersal seine fishing is of dynamic nature a time-domain formulation of the cable dynamics is applied. The *SeineSolver* model implements the method found in [10], which includes a numerical model where the cable dynamics are described as a collection of hinged rigid bodies. The *SeineSolver* tool uses a seabed contact model from *FhSim* [9] which calculates the reaction force resulting from an overlap between a cylinder element and the seabed surface. The normal force leads to a transversal friction force modelled by a friction coefficient. Time integration is performed with a simple forward Euler scheme [11] using a time-step of 0.001 sec. The model behind *SeineSolver* and it validation against flume tank experiments is thoroughly described in [12].

2.2 Model for how Fish Reacts to an Approaching Seine Rope at the Seabed

To be able to predict the effect the seine ropes have on the catch performance of demersal seine fishing by simulation we need a model for how fish near to the seabed reacts to an approaching seine rope. Little information exists for demersal seining but far more observations have been conducted for bottom trawling. The ability of trawls sweeps on the seabed to herd cod into the centre of the trawl are demonstrated in [13]. Cod reacts with an avoidance response when the sweep wire approaches it. This can be interpreted as the cod would keep at least some distance away from an approaching threat, in this case the sweep wire. In line with [14] it can be expected that the cod on average will react by swimming in a direction perpendicular to the approaching wire. We will assume that cod reacts in a similar way to an approaching seine rope during demersal seining. Therefore we will for a first simple model assume that if the seine rope gets closer than a distance l_{min} to the cod it will swim a distance l_{move} from its current position further away from the seine rope in a direction that is perpendicular to the approaching rope. Figure 2 illustrates this behaviour of fish to an approaching seine rope. We will assume no reaction from the cod if it has as a distance to the rope that is greater than l_{min}. In addition we assume that the cod only react to the part of the seine rope which is on the seabed.

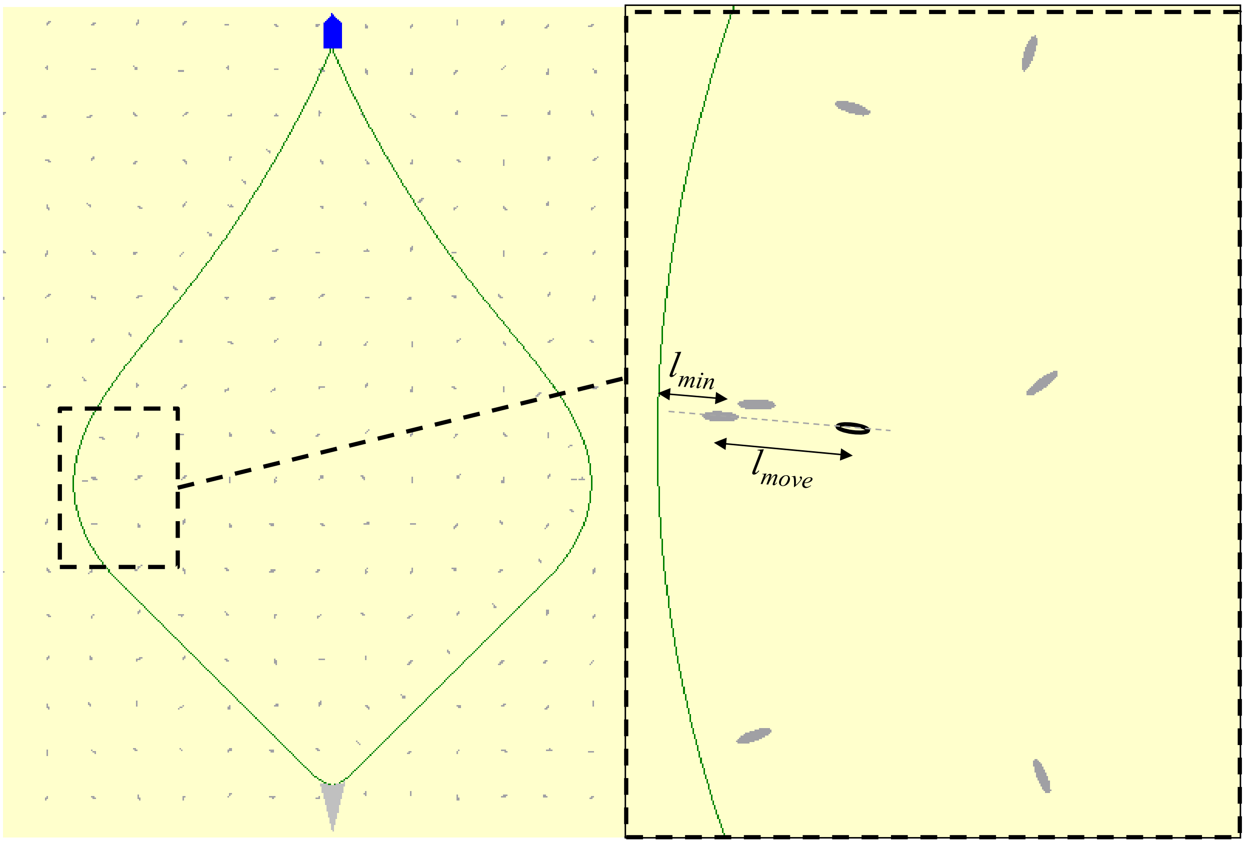

Figure 2: Fish (grey ellipses) reaction to an approaching seine rope (green curve). The zoomed picture on the right side illustrates that when the seine rope gets closer to the fish than the distance l_{min} it reacts by swimming the distance l_{move} further away from the seine rope in a direction perpendicular to the seine rope. Seine net, fishing vessel and fish aggregations are scaled up compared to the length of the seine ropes for illustration purposes.

To account for that all cod might not always react with the avoidance response along the seabed every time the seine rope gets closer than l_{min} to it, we will assume that there will be a small probability p_{raise} for the cod instead of moving along the seabed when approached by the seine rope will react by raising the distance l_{move} up from the seabed for a short while before returning close to the seabed again meanwhile the seine rope passes beneath it. Based on these considerations the probability that the fish will be herded along the seabed for an incidence where the seine rope on the seabed get closer than l_{min} to it will be $p_{herd} = 1.0 - p_{raise}$. Therefore, the cod reaction to the seine rope approaching it will, for each incident when the ropes distance to the fish becomes smaller than l_{min}, can be modelled by a binomial process with probabilities p_{herd} and $1.0 - p_{herd}$ where the cod reacts by respectively moving a distance l_{move}, along the seabed further away and perpendicular from the seine ropes (herding response) or an avoidance response letting the seine rope pass beneath the fish. For the current study we will assume l_{min} = 1.5 m. This value has been selected based on experience on how cod typically are herded in front of the ground-rope during demersal trawling, since underwater recordings conducted in Norwegian bottom trawl fishery targeting cod show that cod often try to maintain a distance of 1-2 m ahead of the ground rope. We will for the current study assume l_{move} to be twice l_{min}. For simplicity, we will for explorative purpose for the current study assume that the cod reacts with a herding response each time the seine rope gets too close to it. This means we will fix p_{herd} at 1.0.

2.3 Simulating the Collection Phase of Demersal Seine Fishing

The model for fish reaction to an approaching seine rope was implemented in a software tool *SeineFish*. *SeineFish* simulates the collecting phase for a demersal seine fishing operation. To do so *SeineFish* uses external generated information on the physical behavior of the seine ropes. This information is obtained with *SeineSolver*. The *SeineSolver* output file contains information on the kinematics of the seine ropes and seine net position continuously during a simulated demersal seine fishing operation. Specifically, the *SeineSolver* output file contains coordinates in 3D for points along the seine ropes for discrete steps in time during the simulated fishing process. Based on this information *SeineFish* models the geometry of the front part of the demersal seine gear continuously in time and space by using a nested linear interpolation technique. Prior to starting the simulated fishing in *SeineFish* the user defines a virtual fish population distributed on the virtual fishing ground in a pattern chosen by the user. For the current study we will for all fishing cases assume that the cod at the start of the simuation are uniformly distributed on the fishing ground and that all are at the seabed. Besides the distribution pattern the user also input the value $fish_{dens}$ (number of fish per m^2 fishing ground) which defines the average density of fish on the fishing ground. For all the simulations in this study we set $fish_{dens}$ at 0.01 m^2 corresponding to on average 100 fish for each 10000 m^2. This value was considered realistic based on total cases of cod obtained during typical demersal seine fishing in Norwegian coastal zone. During the simulated fishing process the distribution pattern of the fish will gradually change due to interaction with the fishing gear. This interaction is simulated by the fish reaction model and controlled by the values chosen by the user for the parameters l_{min}, l_{move} and p_{herd}.

The simulation of the fishing process in *SeineFish* can be characterized as a time-step integration technique (time step = 0.2 sec) where the position and shape of the seine gear on the fishing ground is gradually updated and the interaction with each of the fish individually is simulated according to the procedure described above. During the simulation the value for key indicators is calculated and logged at each step of the simulation. The indicators are: the area encircled by the part of the seine ropes on the seabed ($A_{encirled}$ (m^2)); entry width of the gear (w_{entry} (m)) that is given by the horizontal distance across the fish ground between the two points closest to the fishing vessel on respectively the right and left seine rope that has contact with the seabed; and finally the number of fish $fish_{encirled}$ in the encircled area on the seabed. The simulated fishing process is continuously visualized in *SeineFish* by illustrating the fishing gears shape and position as well as the position and movement of the fish caused by their reaction to the fishing gear. Figure 1 and several of the following figures in this paper have been created based on screen dumps during simulations conducted applying *SeineFish*.

2.4 Fishing Scenario's

To investigate the potential effect of initial seine rope layout pattern on the catch performance for demersal seining targeting cod in coastal zone in Norwegian fishery we simulated four different initial layout patterns: rectangle, square, triangle and diamond (Figure 3).

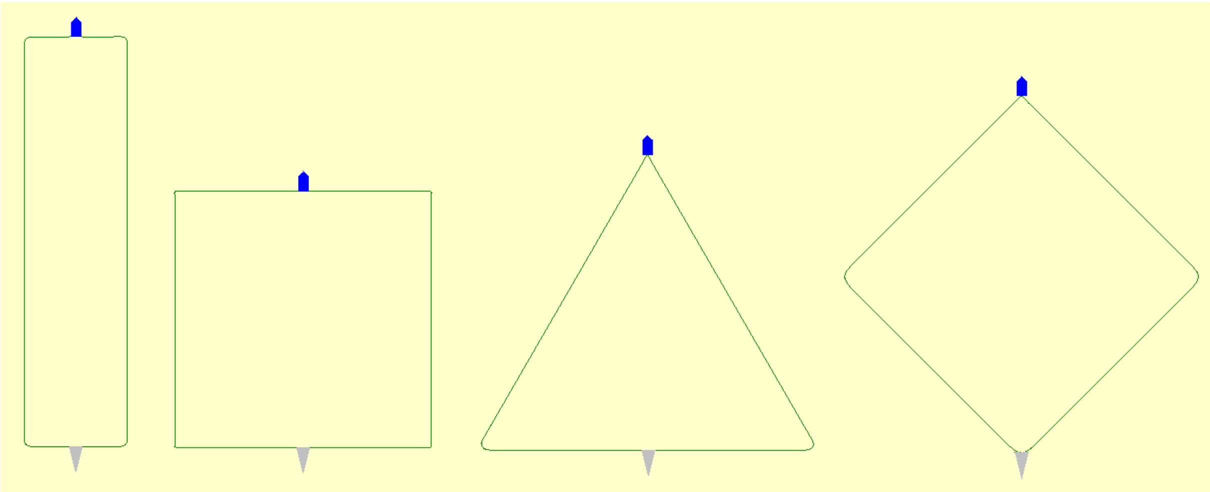

Figure 3: The four different initial layout patterns simulated. From left: rectangular, square, triangular and diamond. Seine net (grey triangle) and fishing vessel (blue pentagon) are scaled up compared to the extent of the seine ropes for illustration purposes (screen dumps from simulations using *SeineFish*).

For each of the four layout patterns the seine ropes laid out on the fishing ground were approximately 2000 m. As such complying with the legislation for the Norwegian coastal fishery and also enabling a fair comparison between cases. The seine rope diameter was 36 mm as typically used in this fishery. Each layout pattern was then deployed with three different haul back procedures to enable investigating the effect on catch performance by haul back procedure. The difference between the three haul back procedures was the time the vessel was towing before starting to winch the seine ropes, respectively 0, 15 and 35 minutes which are realistic values for this fishery. The first case without towing represents the original Danish seine or anchor seine fishing while the two other represents Scottish seining or fly-dragging. In the latter cases the towing speed was two knots and the winching speed 0.9 m/s, which are set-tings also applied commercially in this fishery. For diamond shaped initial layout pattern Figure 4 illustrates the three towing phase cases investigated.

For each of the 12 fishery cases (four different initial layout cases times three different haul in procedures) we first used *SeineSolver* to estimate the physical behavior of the front part of the fishing gear (seine ropes) during the simulated fishing process. The predicted gear behaviours were then subsequently used as input in *SeineFish* to simulate the collection phase for the demersal seine for each of the 12 fishery cases. Since identical fish populations were used for the different fishing cases we could use the values for the encircled number of fish as relative measure for the effectiveness of the fishing process for the different cases. In addition to monitoring the number of fish encircled during the simulated process we also monitored the size of the encircled area and the entry width between the seine ropes. The entry width is important for the effectiveness of a towing phase because it is only through this opening that the initial number of encircled fish can increase since the part of the seine ropes on the seabed will herd the fish outside the seine ropes away.

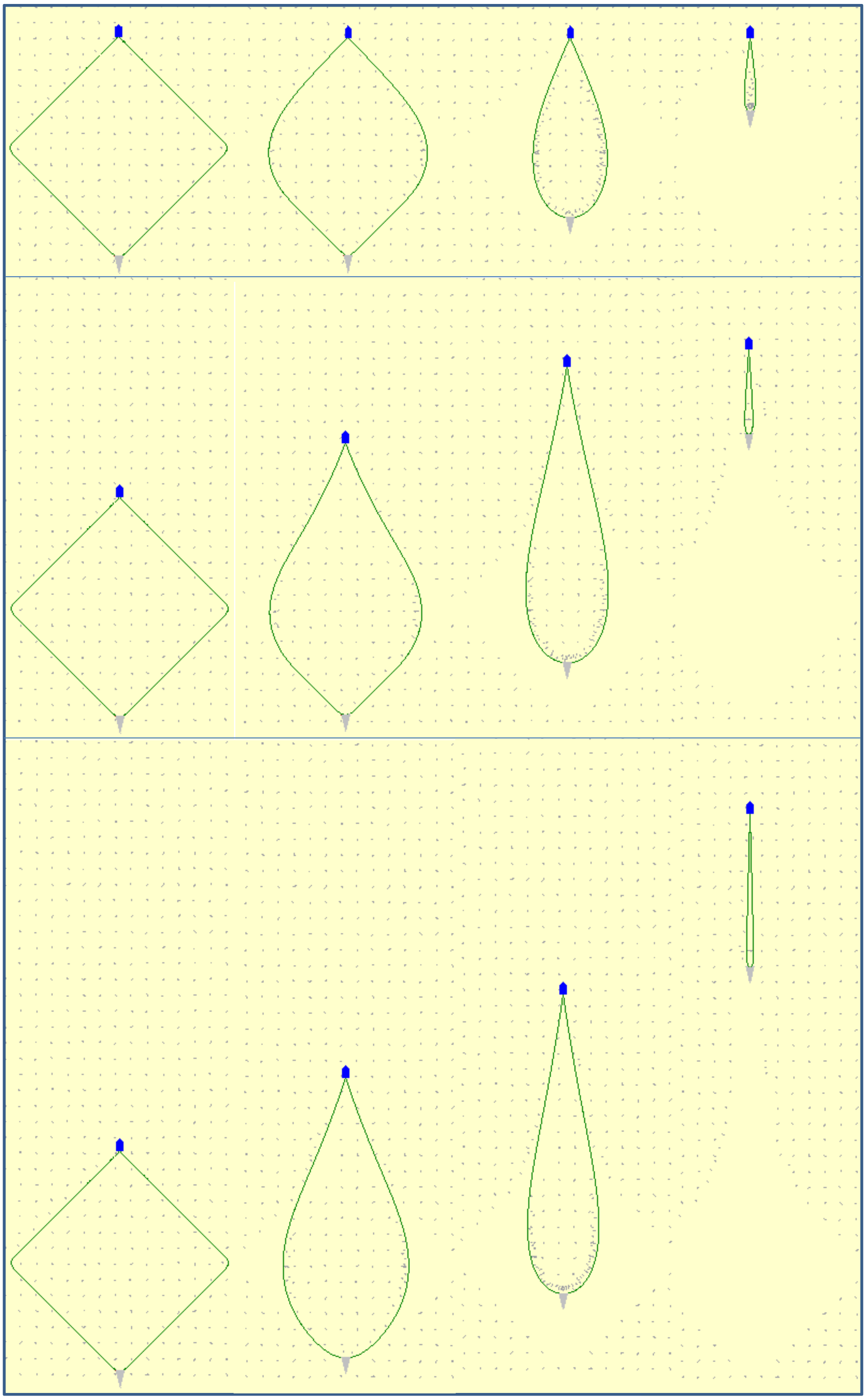

Figure 4: Illustration of the fishing process (from left to right) for each of the three towing phase cases investigated. From top: no towing, 15 minutes towing and 35 minutes towing. Here illustrated for the diamond shaped initial layout pattern. Seine net (grey triangle), fishing vessel (blue pentagon) and fish aggregations (grey dots) are scaled up compared to the length of the seine ropes (green curves) for illustration purposes (screen dumps from simulations using *SeineFish*).

3 Results

3.1 Simulating Fishing Scenarios

Figure 5 illustrates the physical behaviour of the fishing gear during steps in the fishing process for each of the 12 simulated fishing processes.

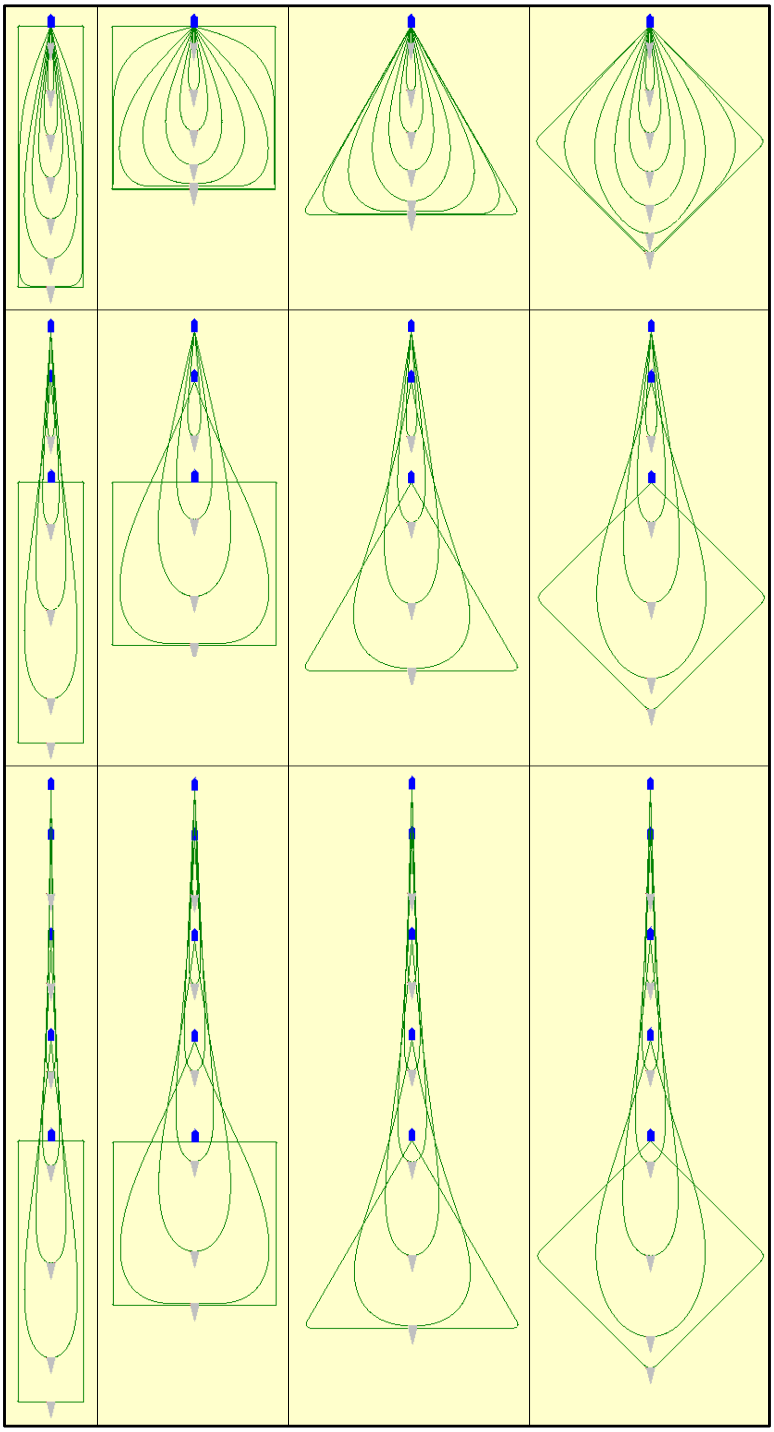

Figure 5: Illustration of the physical behaviour of the fishing gear during different steps of the fishing process for each of the 12 fishing cases investigated. From top to bottom: no towing, 15 minutes

towing, 35 minutes towing. From left to right: rectangular, square, triangular, diamond initial layout pattern. Seine net (grey triangle) and fishing vessel (blue pentagon) are scaled up compared to the length of the seine ropes (green curves) for illustration purposes (screen dumps from simulations using *SeineFish*).

3.2 Number of Fish Encircled

The *SeineSolver* and *SeineFish* tools were applied to predict how the number of fish encircled change during the fishing process when applying each of the four seine rope layout patterns considered for respectively a haul back procedure of 0, 15 and 35 minutes towing before starting winching the seine ropes. From Figure 6 it is evident that for the same seine rope length being deployed on the fishing ground, in this case 2 x 2000 m, the number of fish being encircled by the seine ropes depends strongly on the initial layout pattern. This is the case both for the number of fish being initially encircled and for the number of fish encircled at the end of the fishing process. Specifically we see that the square and diamond layout patterns are predicted to encircle a much higher number of fish than for the triangular and in particular the rectangular pattern.

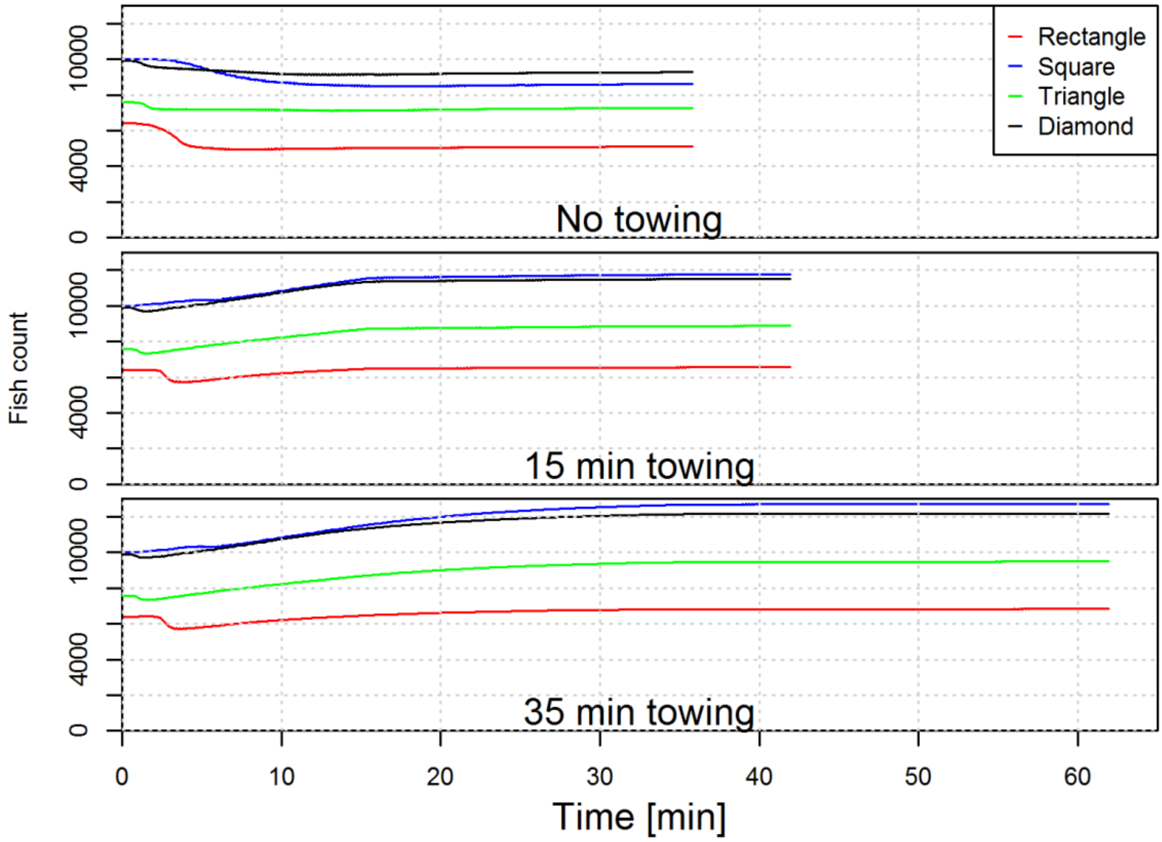

Figure 6: Development in the number of fish encircled by the seine ropes on the seabed (fish count) during the fishing process for deployment of each of the four different initial layout patterns investigated and for each towing phase scenario's.

Figure 6 also illustrates that the number fish increases during the towing phase. But also the marginal benefit of a long towing phase (35 minutes) compared to a shorter (15 minutes). Table 1 quantifies for each of the 12 fishing cases the number of fish being encircled initially, when winching begins and at the end of the fishing process.

Table 1: Number of fish encircled during the fishing process. Numbers in parenthesis are percentage increase compared to value after initial layout.

Layout pattern	Towing time (minutes)	Number of encircled fish		
		Initial	At start winching	At end of process
Rectangle	0	6399	6399(0%)	5098(-20%)
Rectangle	15	6399	6458(1%)	6564(3%)
Rectangle	35	6399	6813(6%)	6837(7%)
Square	0	9999	9999(0%)	8605(-14%)
Square	15	10000	11505 (15%)	11783 (18%)
Square	35	10000	12684(27%)	12739(27%)
Triangle	0	7581	7581(0%)	7270(-4%)
Triangle	15	7582	8681(14%)	8881(17%)
Triangle	35	7582	9456(25%)	9498(25%)
Diamond	0	9897	9897(0%)	9270(-6%)
Diamond	15	9897	11319(14%)	11526 (16%)
Diamond	35	9897	12150(23%)	12192 (23%)

The rectangular and triangular layout patterns are predicted to initially encircle respectively only 64% and 76% of the number of fish being encircled with the square and diamond layout patterns (Table 1). At the end of the fishing process this difference is increased further and depends also on which of the three simulated haul back procedures that has been applied. Based on the values in Table 1 it can for example be calculated that for respectively 0, 15 and 35 minutes towing before winching that the rectangular layout end up encircling only respectively 59%, 56% and 54% of what could be expected to be obtained with the square layout pattern. What is obtained by towing and winching with regard to the number of fish encircled compared to the number of fish initially encircled the values in Table 1 demonstrate that this strongly depend on the layout pattern employed for the fishing process. For the rectangular layout it is predicted that the encircled number of fish is only increased by respectively 3 and 7% dependent on if the towing time applied is 15 or 35 minutes. Contrary for square, diamond and triangle patterns are the increases being predicted to be respectively 18, 17 and 16% for 15 minutes towing and 27, 25 and 23% for 35 minutes towing. In general it is found that without towing the number of encircled fish will decrease from the initial value with a percentage that depends on initial layout pattern. This illustrates the benefit of a towing phase as the drop in encircle number of fish can be as big as 20%.

3.3 Area Encircled on the Seabed by the Seine Ropes

To help understanding the difference in performance of the layout patterns regarding their ability to encircle fish during the fishing process it can be useful to look on how some of the geometrical properties for the gear develop during the fishing process. The first to look at is the area encircled by the seine ropes on the seabed. Figure 7 illustrates for a towing phase of 15 minutes as an example the development in area encircled by seine ropes on the seabed (green filled areas on Figure 7).

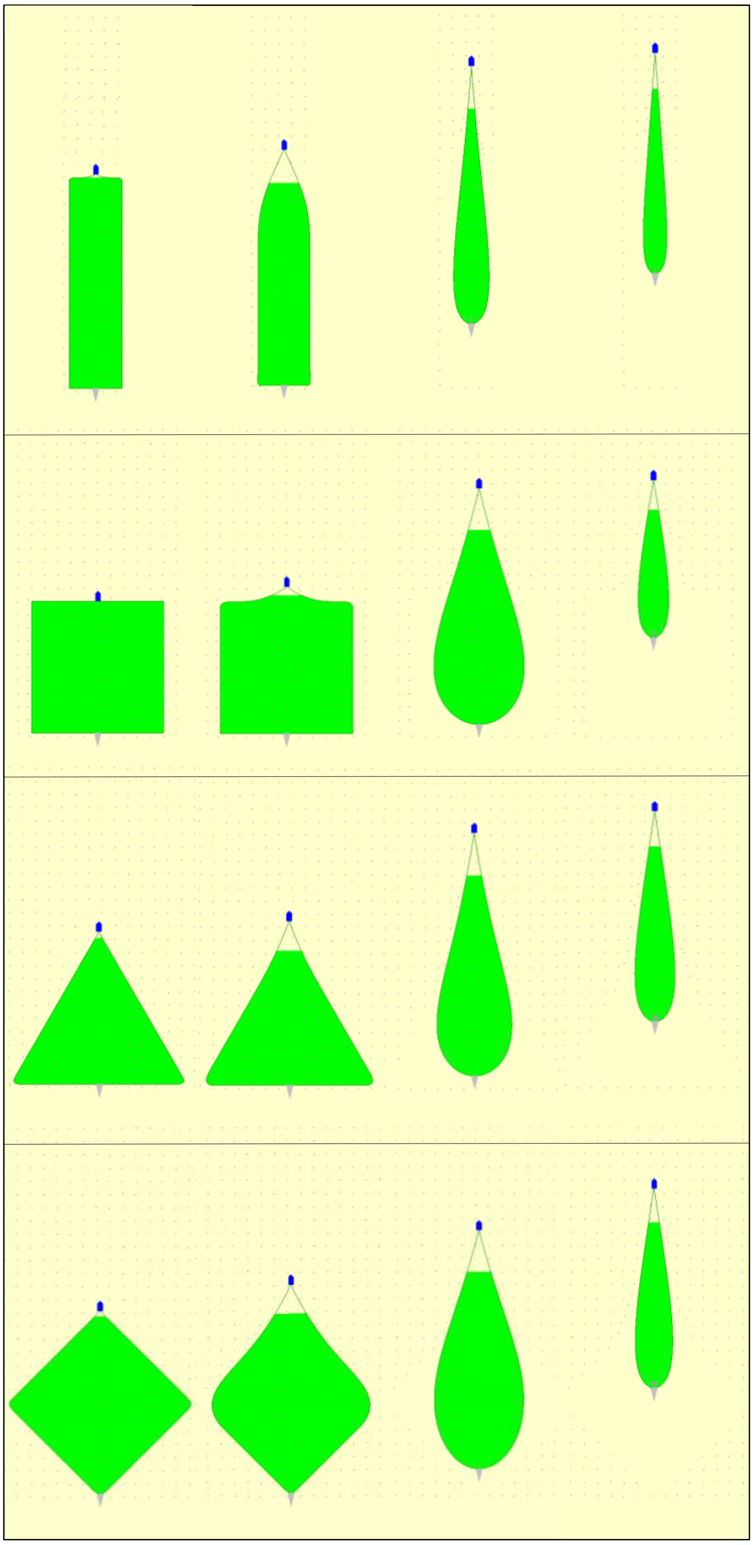

Figure 7: Illustration of the development in the area encircled (green area) by the seine ropes on the seabed during the fishing process (from left to right) for each of the four initial layout patterns (from top to bottom). Here illustrated for 15 minutes towing phase. Seine net (grey triangle), fishing vessel (blue pentagon) and fish aggregations (grey dots) are scaled up compared to the length of the seine ropes (green curves) for illustration purposes (screen dumps from simulations using *SeineFish*).

The difference in the development in the encircled area for the different initial layout patterns during the fishing process is clear (Figure 7). The development in entry width (where the seine ropes are lifted from the seabed) into the encircled area is also seen in Figure 7 and the narrowness of it is clear. This illustrates the challenge of benefitting from a long towing phase. But also why a short towing phase benefits the catch compared to not towing at all. The reason for this is that when the seine ropes are first pulled at by the vessel parts of the seine ropes lift of the seabed leading to a decrease in the encircled area and thereby of the collected fish. During the first part of a towing phase this amount of fish is regained through the entry width and the area covered through this. This phenomenon is also clear from Figure 6 which shows the drop in the initial number of fish encircled when the vessel starts pulling at the seine rope. Without any towing phase (Figure 6 top) this loss is never regained during the remaining fishing process. Contrary with a towing phase of 15 or 35 minutes this loss is re-gained (Figure 6 middle and bottom). Figure 8 quantifies the development in the encircled area during the fishing process for each of the 12 fishing cases investigated.

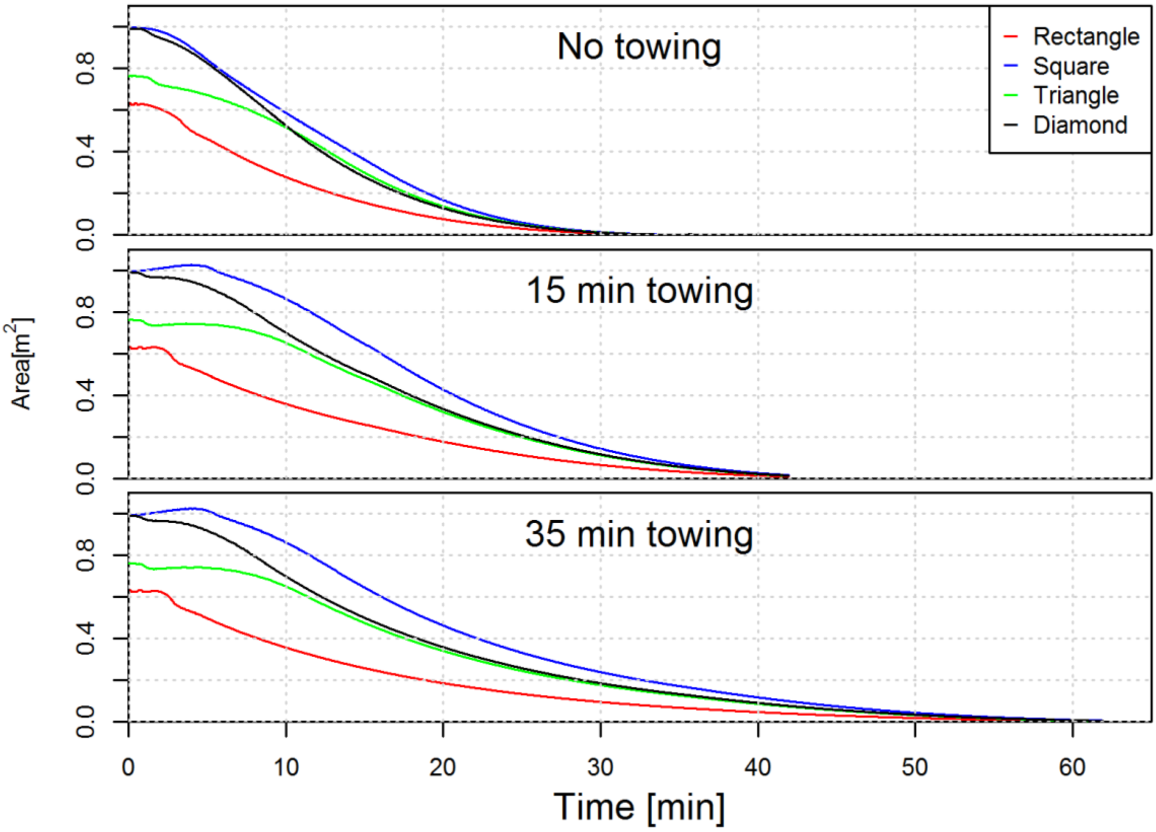

Figure 8: Development in the area encircled by the seine ropes on the seabed during the fishing process for of each of the four different initial layout patterns investigated and for each towing phase scenario's.

From Figure 8 it is clear the initially encircled area depends strongly on layout pattern applied and we can as expected fully explain the differences in initial number of fish being encircled between the different layout patterns (Table 1). We see how the seine rope encircled area gradually decreases during the fishing process and when combined with Figure 6 would mean increase in the density of fish in the encircled area. It is seen for a fishing process without a towing phase (Figure 8 top) that the encircled area diminishes earlier than if a towing phase of some duration was included in the fishing process (Figure 8 middle and bottom). However to understand the increase in number of fish encircled during the fishing process we need to look on another geometrical indicator for the gear. We have to look on the entry width to the encircled area since it is through this that additional fish enters the encircled area when the seine ropes are dragged forward to cover additional area on the seabed. Figure 9 quantifies the entry width during the fishing process.

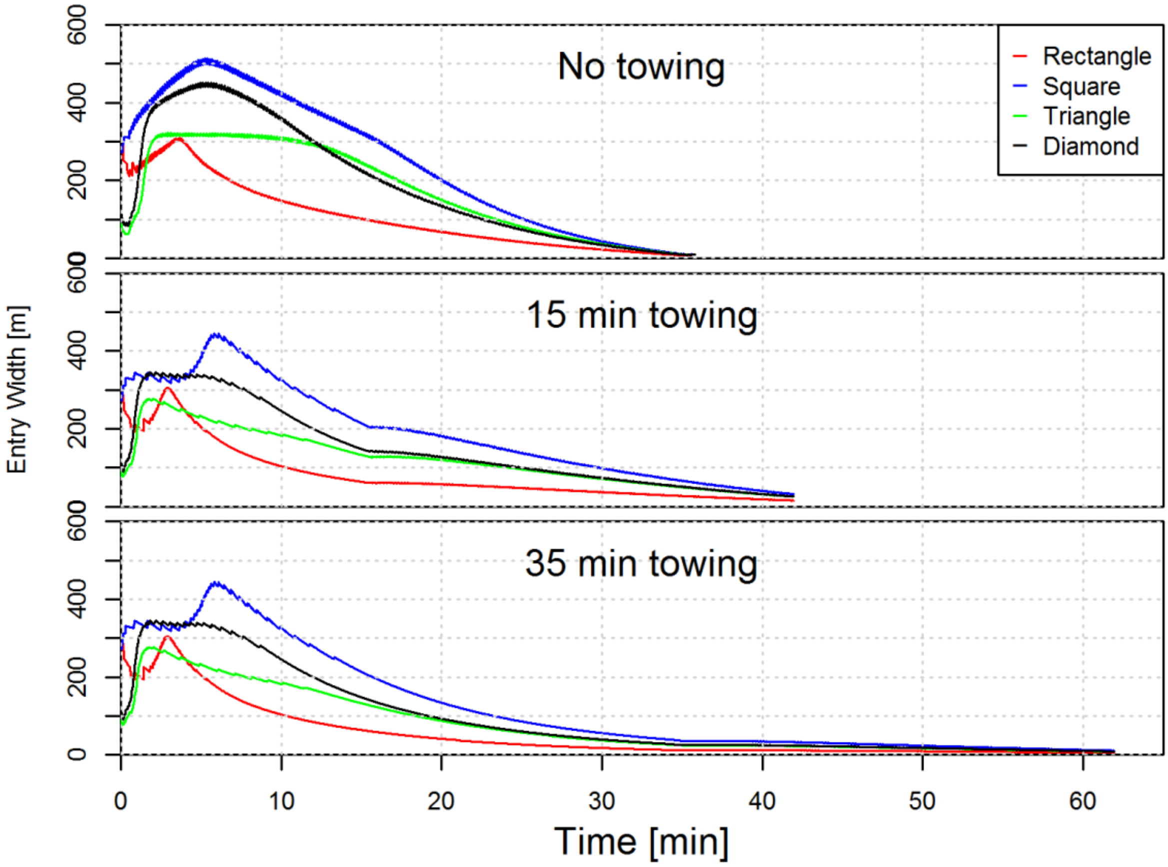

Figure 9: Development in the entry width into area encircled by the seine ropes on the seabed during the fishing process for of each of the four different initial layout patterns investigated and for each towing phase scenario's.

From Figure 9 is it evident that the predicted entry width for much of the fishing phase is far smaller for the rectangular layout when compared to the other layouts and in particular with the square. This provides a potential explanation for why the predicted increase in number of fish encircled increase far less for this layout compared to each of the other layouts (see Table 1). It is interesting to see that the initial entry width is big for the rectangular layout but that quickly decreases while the opposite happens for the diamond layout.

4 Discussion

In this study we have investigated how the catch performance for a demersal seine fishing operation may be affected by the initial seine rope layout pattern and by the haul back procedure. Specifically we have investigated the effect of including a towing phase of some duration since this is one of the major differences between the variants of the demersal seine fishing method. We tried to make our study as realistic as possible to represent demersal seining targeting cod in Norwegian coastal zone. Our study was based on applying sequentially two different simulation models. The first *SeineSolver* for estimating the physical behaviour of the seine ropes during an artificial fishing process and the second *SeineFish* which uses the output from *SeineSolver* to simulate fishing when the gear is deployed on a virtual fishing ground with a prescribed fish population distributed on it. *SeineFish* implements a simple model for how cod is assumed to react to an approaching seine rope dragged over the seabed during a demersal seine fishing operation. This model may be too simplistic but we expect that it any-way will estimate fairly realistic how different layout patterns and haul back procedures may affect the catching effectiveness of a demersal seine as least relative to each other. Further, this behavioural model can easily be made more complex by for example considering endurance of the fish after they have been forced to swim over some distance. An easy way to implement this would be to make p_{herd} a decreasing function of the total distance the fish has been forced to swim. Further p_{herd} can be made dependent on the size of the fish.

One obvious advantage of using simulation for our study is that we have control over what is on the fishing ground. Specifically this means that we were able to test the different fishing cases on identical fishing conditions with respect to number of fish and spatial distribution on the fishing ground which is essential for being able to conduct a fair comparison between the different fishing cases tested. It further provides a cheap and fast method for exploring how different aspects can affect the effectiveness of demersal seine fishing. In this study we found that the effectiveness of demersal seining in the Norwegian coastal zone targeting cod will depend on the seine rope layout pattern applied. Specifically we predict that the rectangular layout we deployed, which is not unrealistic compared to what is applied in the commercial fishery [17], will only catch 54-56% of the cod that would be obtained with a square layout pattern. This highlights the importance of considering initial layout pattern when planning demersal seine fishing at least when the cod are uniformly distributed on the fishing ground as assumed in our simulations. Our results also demonstrated that the length of the towing phase can significantly affect the total catch but that the extent also depends on the layout pattern applied.

Simulation models have previously proven to be useful for predicting fish capture with active fishing by combining models for the physical behaviour of the fishing gear with models for fish behavior to the gear. To our knowledge those models have focused on trawls and mainly size selectivity in codends. One such model for codend is the selectivity simulator *PRESEMO* [18] which have used input about the physical behavior of the gear from respectively the model of Priour [15] or the model of O'Neill [16]. To our knowledge this is the first time that such combination of physical and behavioural models have been applied to investigate aspects of effectiveness of demersal seining.

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