HOW DO DIFFERENCES IN SEINE ROPE LAYOUT PATTERN AND HAUL-BACK PROCEDURES AFFECT THE EFFECTIVENESS FOR DEMERSAL SEINING?

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Abstract

Demersal Seining is an active fishing method applying two long seine ropes and a seine net. The seine ropes and net are deployed in a specific pattern encircling an area on the seabed. In the first part of the haul-back procedure (i.e. the closing/herding phase during fly-dragging) the fishing vessel moves forward and the total swept area increases while the shape and size of the encircled area gradually changes. When the captain believes the net-wings are closed, the rope drums are activated and hauling speed increased. This operation also affects the area which is swept by the seine ropes. It is of interest for the fishermen to improve knowledge about how the catching performance is related to the area swept by the seine ropes and in particular how it depends on the initial layout patterns and on the applied haul-back procedure. The current study investigates this subject by applying a simulation model for demersal seine fishing. The demersal seine fishing is dynamic of nature and therefore a dynamic model is applied for simulating the physical behaviour of the seine ropes during the fishing process. Information about the seine rope behaviour is then used as input to another simulation tool which predicts the catching performance of the demersal seine fishing process. This tool implements a simple model for how fish at the seabed reacts to an approaching seine rope. The tools are applied to investigate catching performance for a typical Norwegian demersal seine fishery targeting cod (*Gadus morhua*) in the coastal zone.

Keywords

Simulation, Demersal seining, Cod

Introduction

Demersal seining is a commonly applied fishing method to harvest species that live close to the seabed. E.g. in Norwegian fishery; cod is the most important species in the white fish fishery when measured in both tonnes landed and in value [7]. About 20% of the Norwegian cod quota is caught by demersal seining; the Norwegian style fly dragging. Thus, knowledge about the physical behaviour of this type of gear and its ability to collect fish for the seine net is very relevant. 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) weighting more than 2 kg/m, are placed on the seabed often in a quadrilateral pattern in order to encircle the targeted fish [11]. 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 when 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.

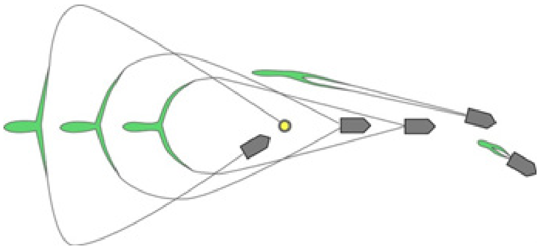

Figure 1
Demersal seine fishing procedure [3].

The catching performance of a demersal seine fishing operation depends to a large extent on the area on the seabed which is swept and encircled by the seine ropes during the fishing process and by the efficiency the seine ropes are able to herd the fish into and subsequently maintain them in the path of the 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 during the fishing process leads increased number of fish in it is therefore important for an efficient fishery. Thus, understanding the physical behaviour of the seine ropes and how this behaviour gradually leads to increased number of fish being encircled are important aspects of the demersal seine fishing process. The current study investigate this subject by applying a simulation model for demersal seine fishing predicting the amount of fish being collected between the seine ropes during the fishing process. The 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 typical Norwegian demersal seine fishery targeting cod (*Gadus morhua*) in the coastal zone.

Material and Methods

Tool for simulating the physical behaviour of the seine ropes. The dynamics of the demersal seine 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 which 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 [10]. 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 [5], which contains a model where the cable dynamics are formulated as a collection of hinged rigid bodies. The *SeineSolver* tool further uses an existing bottom contact model from FhSim [10] which calculates a reaction force normal to the bottom from an overlap between element cylinder geometry and the flat bottom surface. The normal force results in a transversal friction force modelled by a friction coefficient with value in the range 0.0 to 1.0. Time integration is performed with a simple forward Euler scheme [2] and a time-step of 1e-3s. The model behind *SeineSolver* and it validation against flume tank experiments is thoroughly described in [6].

Model for fish reaction 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 center of the trawl are demonstrated in [12]. 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 [13] 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. 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. 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 become smaller than l_{min}, be modelled by a binomial process with probabilities p_{herd} and $1.0 - p_{herd}$ that the cod react by respectively a move l_{move}, relative to its current position of the fish, away from the seine along the seabed perpendicular to the seine rope and an avoidance that lets the seine rope pass beneath it. 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 (personal comment: Manu Sistiaga). 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.

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 (SSO-file) contains information on the kinematics of the seine ropes and seine net position continuously during a simulated demersal seine fishing operation. Specifically the SSO-file contains for discrete steps in time during the simulated fishing process predicted coordinates in 3D for points along the seine ropes. 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 simulation 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 $0.01m^2$ 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 (personal comment: Manu Sistiaga). 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.

Fishing cases. 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 2).

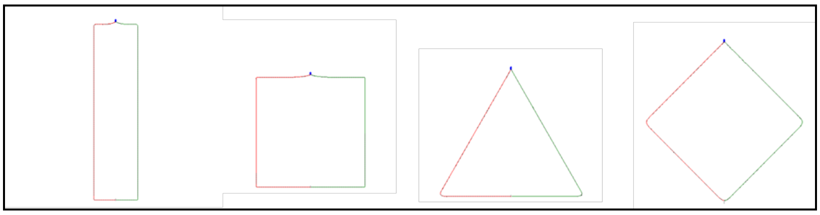

Figure 2

The four different initial seine rope layout patterns simulated. From left: rectangular, square, triangle and diamond.

For each of the four layout patterns (Figure 2) the seine ropes laid out on the fishing ground were approximately 2000 m for each of the ropes, 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 two different haul back procedures to enable investigating the effect on catch performance by haul back procedure. The difference between the two haul back procedures was the time the vessel was towing before starting to winch the seine ropes, respectively 15 and 35 minutes which are realistic values for this fishery. In both cases the towing speed was 2 knot and the winching speed 0.9 m/s, which are settings also applied commercially in this fishery. For each of the eight fishery cases 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 behaviors were then subsequently used as input in *SeineFish* to simulate the collection phase for the demersal seine for each of the eight fishery cases. Since identical fish populations were used for the different fishing 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.

Results

Simulating fishing cases. Figure 3 illustrates specific steps in the fishing process for one of the eight simulated fishing processes.

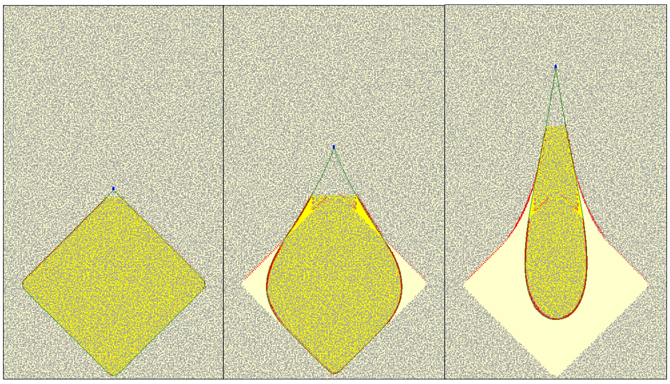

Figure 3

Screen dumps from *SeineFish* during simulation of one of the fishing cases (diamond layout).

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 with 15 and 35 minutes towing before starting winching the seine ropes. From Figure 4 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.

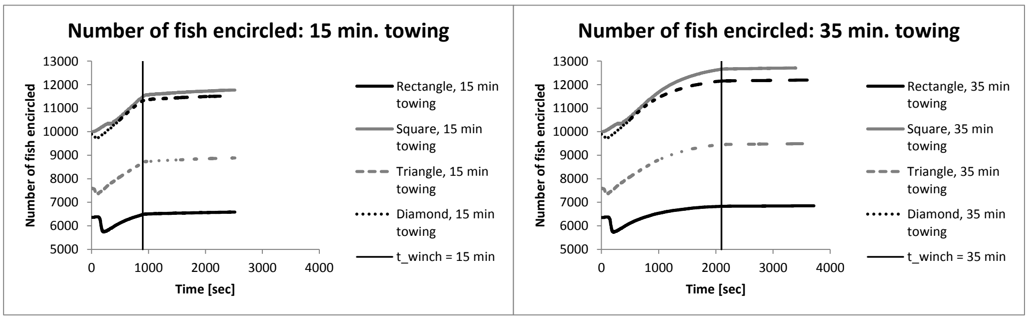

Figure 4

Number of fish encircled by seine ropes on the seabed during the fishing.

Figure 4 also illustrates that the number fish increases during especially the towing phase. Table 1 quantifies for each of the eight 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	Towing time	After initial layout	Start winching	End of operation
Rectangle	15 min.	6360	6487(2%)	6582(3%)
Rectangle	35 min.	6352	6828(7%)	6853(8%)
Square	15 min.	10000	11493(15%)	11772(18%)
Square	35 min.	10000	12657(27%)	12708(27%)
Triangle	15 min.	7590	8680(14%)	8885(17%)
Triangle	35 min.	7590	9450(25%)	9495(25%)
Diamond	15 min.	9897	11307(14%)	11529(16%)
Diamond	35 min.	9897	12152(23%)	12198(23%)

The rectangular and triangular layout patterns are predicted to initially encircling only respectively approximately 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 two simulated haul back procedures that has been applied. Based on the values in Table 1 it can for example be calculated that for respectively 15 and 35 minutes towing before winching that the rectangular layout end up encircling only respectively 56% and 54% of what could be expected to be obtained with the square layout pattern. Regarding what is obtained by towing and winching on the number of fish encircled compared to the number which was 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 8% dependent on the towing time applied. 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 25% for 35 min. towing.

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 5).

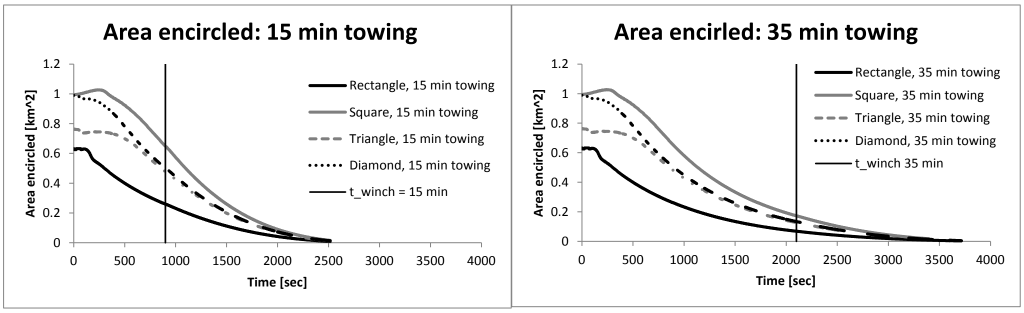

Figure 5
Area encircled by the seine ropes on the seabed during the fishing process.

From Figure 5 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 4 would mean increase in the density of fish in the encircled area. 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 6 illustrates the entry width during the fishing process.

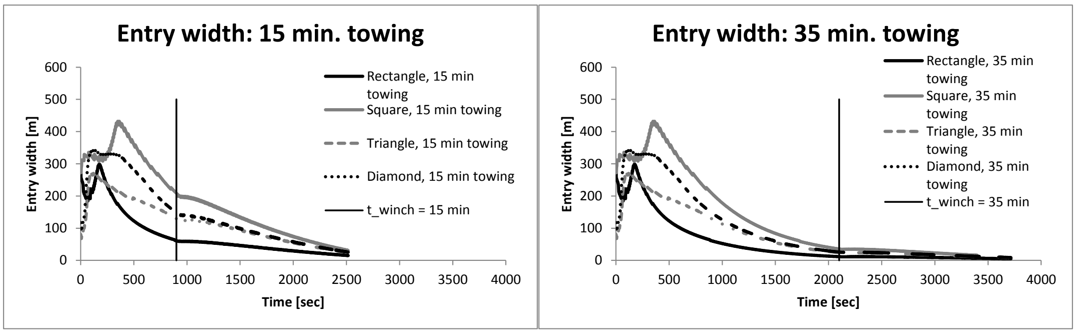

Figure 6

Entry width to the encircled area during the fishing process.

From Figure 6 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.

Discussion

In this study we 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. 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 anyway will enable to 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 [1], 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 [4] which have used input about the physical behavior of the gear from respectively the model of Priour [9] or the model of O'Neill [8]. But, to our knowledge is this the first time that such combination of physical and behavioral models have been applied to investigate aspects of effectiveness of demersal seining.

Acknowledgements

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