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Titill: Use of Underwater TV-survey to monitor trawl marks on Nephrops grounds

Höfundur: Stefanie Haase, Haraldur Arnar Einarsson, Jónas P. Jónasson og Julian M. Burgos

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Ágrip
Fjallað er um álag af völdum veiðarfæra á humarslóð. Skoðað var myndefni frá fyrsta humarholu-leiðangrinum árið 2016 þar sem holur humarsins voru taldar með myndavélasleða. Togförin voru flokkuð með nýrri aðferðafræði í 5 gerðir, dýpi þeirra mælt og stig í aldri metið. Alls sáust 609 ummerki frá veiðarfærum á þeim 85 stöðvum sem teknar voru. Gerð A, að öllum líkindum eftir toghlera, var algengust með yfir helming tilvika. Dýpt faranna var að jafnaði um 4 cm, en líkleg för eftir toghlera eða bobbingalengju voru yfirleitt aðeins dýpri. Jákvæð fylgni var á milli fjölda togfara og veiðiálags metið út frá rafrænum afladagbókum. Veiðiálagið var mjög mismunandi en metið var að á jafnaði væri togað 2.1 sinni yfir humarslóðina á 18 mánaða tímabili. Veik neikvæð fylgni var á milli fjölda togfara og sæfjarðarinar *Virgilaria mirabils* en sjaldgæfari sæfjaðrir *Pennatula spp*. voru einnig algengari þar sem minna var af togförum.

Abstract
In this report trawl marks on Nephrops grounds are quantified. Records are from the first underwater TV survey in Icelandic waters carried out in 2016. Trawl marks or furrows identified on the videos were classified with a new procedure into 5 types, the depth of the furrow was measured and also the stage or age of it. All 85 stations from the survey were analysed and in total there were 609 furrows detected as an individual trawl mark. Type A, which is most likely caused by an otter board corresponded to more than half of the observed marks. The depth of the furrows was usually about 4 cm, but marks depicted from otter board or rockhoppers penetrated slightly deeper than other types. A positive correlation was found between the numbers of trawl marks and fishing effort from electronic logbooks. Trawling intensity varied, but on average it was estimated that the area was trawled with a Nephrops trawl 2.1 times over a 1.5 years period. Weak negative correlation was found between density of the sea pen Virgilaria mirabils *and trawl marks, but the less common* Pennatula spp. *were found in higher abundance where fewer furrows were observed.*

Lykilorð: *Bottom impact, Nephrops trawls, trawl marks, VMS*

Undirskrift verkefnisstjóra: Haraldur A Einarsson	**Undirskrift forstöðumanns sviðs:**

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Introduction

Bottom trawling is ranked as one of the most habitat-altering fishing techniques. Trawling can produce several types of disturbances on the sea bottom: in addition to indirect effects such as post-fishing mortality and long-term changes in benthic communities, there are also direct effects like the displace of substrate, re-suspension of sediment, damage and destruction of benthic organisms and the disposal of discards and processing waste (Jones, 1992). The degree and duration of the disturbances vary with the weight and angle of the trawling gear, towing speed, substrate type and strength of currents and tides (Jones, 1992). The tracks of otter boards can be as deep as 0.3 m depending on the substrate (Krost, Bernhard, Werner, & Hukriede, 1990) and represent the most significant alteration on the seafloor, although other components of the gear can also affect it considerably (Krost et al., 1990; Rosenberg et al., 2003).

Fishing gear generates sediment clouds that can smother the benthos (Jones, 1992). This might alter seabed complexity and reduce benthic production (Buhl-Mortensen et al., 2016; Jennings, Dinmore, Duplisea, Warr, & Lancaster, 2001; Watling & Norse, 1998). Additionally, mixing upper surface layers with deeper anoxic layers can result in anaerobic sections and therefore harm benthic species (Jones, 1992). These anaerobic areas arise also if waste is dumped overboard after processing the catch, resulting in oxygen depletion

The demersal *Nephrops* (*Nephrops norvegicus*) fishery off the South coast of Iceland (63°N - 65°N and 14°W - 24°W) was chosen as a case study to evaluate the impact of trawling on the seabed. *Nephrops* is commercially fished and supports annual landings of between 1000 - 2500 tons (MFRI, 2017). Several of the vessels in the *Nephrops* fishery use two trawls, connected with a heavy load (the clump) between them. The small meshed *Nephrops* trawl is usually not equipped with rockhoppers but a thick ground-rope. Trawling marks can be expected from the otter boards and the clump as well as the net itself, especially the codend. Nevertheless, it is possible that other vessels that operate in the area targeting different species may use gear equipped with rockhoppers producing rockhopper marks. Bottom trawling for *Nephrops* is conducted at depths between 100 - 300 m (Eiríksson, 1999). Towards the east of the *Nephrops* grounds (between 14°W and 18°W) the bottom sediment contains at least 10 - 70% clay and silt and up to 1% gravel (Boulton, Thors, & Jarvis, 1988; Eiríksson, 1999). These muddy areas are characterized by straight troughs, where *Nephrops* is usually found, separated by shallower sandy areas that are uninhabitable for this species (Eiríksson, 1999). The west of the *Nephrops* grounds (19°W - 24°W) is dominated by muddy banks, partly interrupted by deeper ravines (Eiríksson, 1999).

Most knowledge on the effect of bottom trawling on the sea bottom either results from fishing gradient studies that compare similar habitats subjected to different fishing intensities (Hinz, Prieto, & Kaiser, 2009; Mangano et al., 2014; O'Neill & Ivanovic, 2016) or from Before-After-Control-Impact (BACI) experiments, where observations are made before and after a trawling event (Kenchington et al., 2006; O'Neill & Ivanovic, 2016; Pitcher, Burridge, Wassenberg, Hill, & Poiner, 2009). Side scan sonars are used regularly to estimate the density and depth of trawl marks (e.g. Lucchetti, Sala, and Jech 2012; Palanques et al. 2014; Schwinghamer et al. 1998). Nevertheless, only marks caused by otter boards can be recognized since marks must reach a certain depth to be visible on the side scan. It is impossible to differ between shapes and stages of trawl marks. However, other methods can be used to get a qualitative evaluation of the trawl marks and the surrounded area and fauna, including sediment cores, diver observations, and the examination of videos from cameras mounted on sledges and Remote Operated Vehicles (ROVs) (e.g. Boulcott, Millar, and Fryer 2014; Buhl-Mortensen et al. 2016; Collie, Escanero, and Valentine 2000; Dellapenna et al. 2006; O'Neill and Summerbell 2011).

In this study, footage from the annual *Nephrops* survey of 2016 was used to quantify and qualify the effect of *Nephrops* bottom trawling on the seafloor in a fishing gradient study. Trawl marks or furrows were classified into different groups and stages to analyze the origin, age and impact of the tracks. In addition, the abundance of the sea pens (*Virgilaria mirabilis* and *Pennatula spp*) was estimated from the underwater video. The number of trawl marks and the abundance of sea pens can then be compared to the intensity of the trawling activity in that area, obtained from vessel monitoring systems (VMS) to evaluate the impact of *Nephrops* fishing on this area.

Material and Methods

Video recordings to estimate the influence of trawl marks

Video sampling took place as part of the first UWTV (underwater television) survey from 18 - 22 April and 7 - 17 June of 2016. There were in total 85 stations, laid out on a fixed grid, established on Nephrops fishing areas identified using VMS data off the South coast of Iceland (63°N - 65°N and 14°W - 24°W). The distance between stations was approximately 4.5 nm. The underwater HD camera was mounted at 45° on a sledge which was towed at speeds of 0.5 - 1.5 knots behind the vessel. Cable was payed in or out to achieve a steady and smooth tow. To measure distances, two lasers were mounted at the sledge, with a distance of 95 cm apart (Figure 2). At each station video footage was recorded for ten minutes. The distance traveled over ground was estimated by vessel position (DGPS) and an odometer. All trawl marks were registered and classified into four states (***Table***) and six types, based on similarities after reviewing most of the stations (***Figure 1***). Type A represents trawl marks with a higher hill on one side of the furrow where the displaced volume is deposited. Type B is used to classify trawl marks with a “U”- or “V” shape. The deepest part is the narrowest part. Type C described trawl marks with a wider and flatter bottom part than type B. Trawl marks of type D consisted of two hills or two furrows very close to each other with a small furrow or hill, respectively, in between them. Wavelike trawl marks composed of several smaller furrows were classified as Type E. Type F was chosen if the trawl mark could not be classified as any of the types A-E. The states were used to assess the age of the trawl mark assuming that the stage increased with age. Additionally, the depth of different types of furrow was calculated if the furrow was crossed simultaneously by both laser points requiring a horizontal orientation of the trawl mark. By knowing the difference in laser points between widest (highest point of the furrow) and narrowest (lowest part of the furrow) points, and the angle of the camera (47.5° in average) it was possible to calculate the depth (see Figure 2 for illustration).

The abundance of the two occurring species of sea pens (*Virgilaria mirabilis* and *Pennatula spp.*) was estimated as counts per minute of recordings.

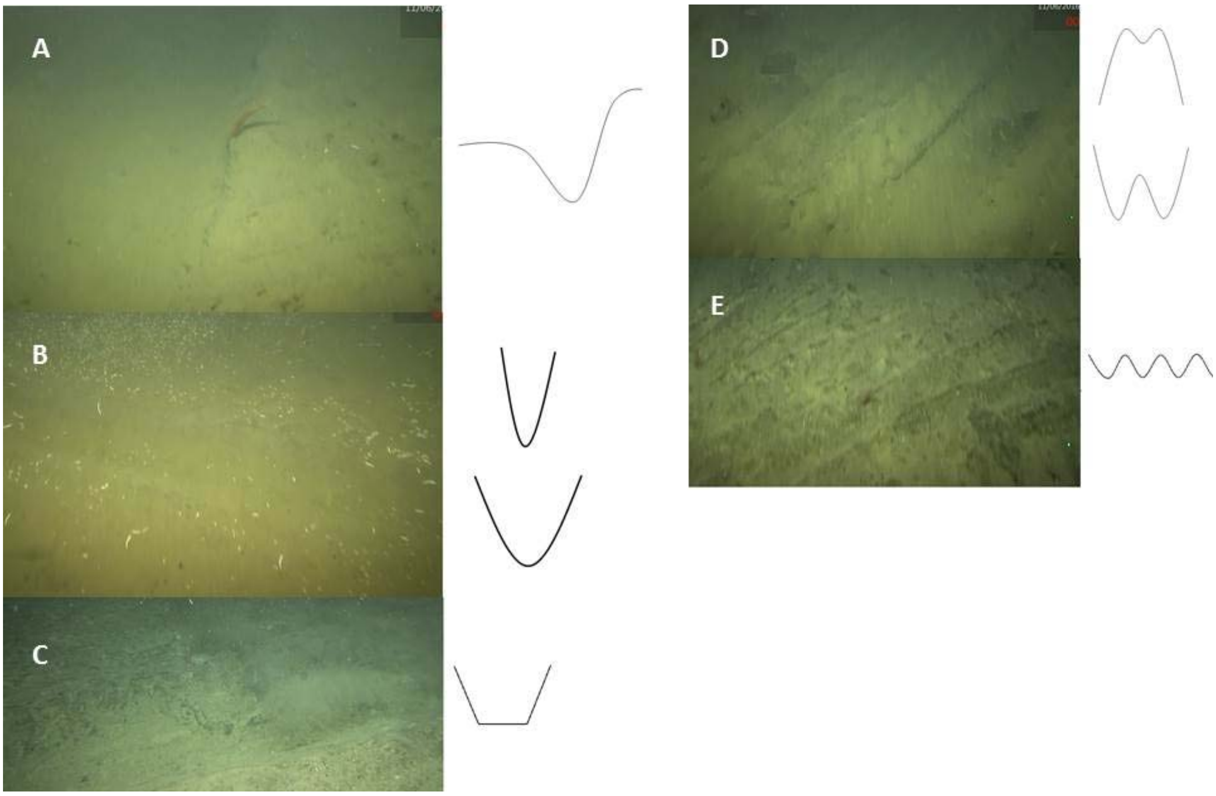

Figure 1. *Classification of different types of trawl marks (A-E), see text for classification.*

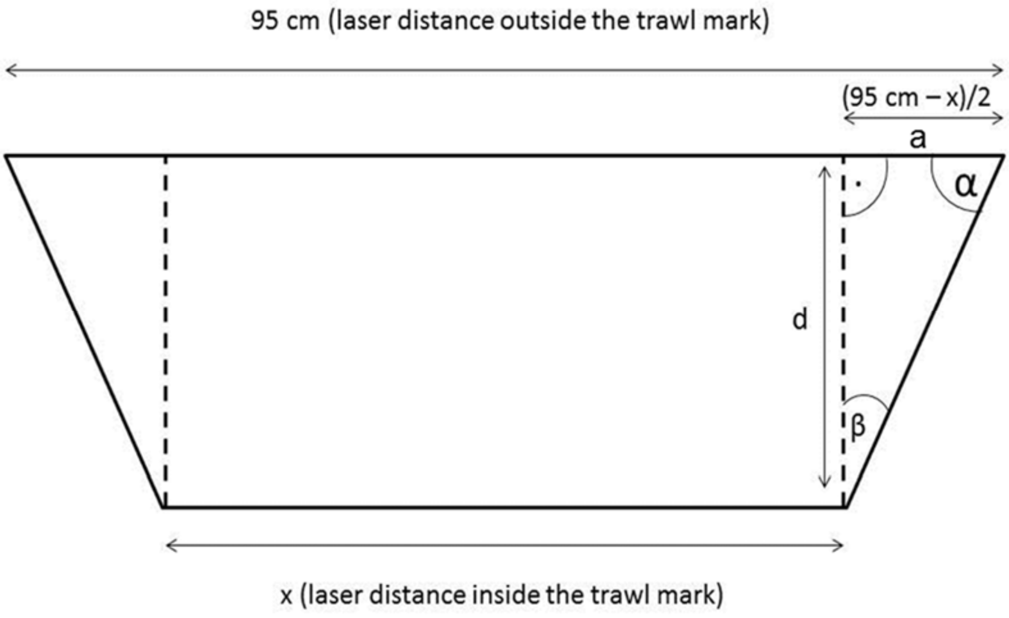

Figure 2. *Illustration for calculating the depth of the trawl mark.*

Table 1. *Classification of different states of trawl marks.*

State	Title	Description
1	distinguished	structure is fresh and detailed
2	started to erode	structure blurs
3	eroded	structure is rounded and soil deposited inmark
4	uncertain	maybe just a bottom feature

VMS data to estimate fishing intensity

The use of Vessel Monitoring System (VMS) is obligatory for all Icelandic vessels. VMS data was obtained for vessels fishing for *Nephrops* (i.e. using *Nephrops* trawls). Data included vessel identification, and location and speed, collected approximately each 10 minutes. Only VMS records with speeds between 1 and 4 knots, considered as indicator of fishing activities, were included in the analysis. VMS data obtained between 2014 and 2016 up to the beginning of the video survey was included in the analyses. Since the average vessel in this analysis tows with an average speed of 2.9 knots, it covers 0.9 km in 10 minutes. Therefore, the resolution of the grid was therefore chosen to be 0.9 km for VMS and trawl mark data. The number of VMS point per grid cell was used as an estimate of fishing intensity. Nevertheless, there is some uncertainty in the estimation, since some vessels are trawling at lower speeds, resulting in multiple VMS points per cell, and some trawl at higher speeds, resulting in missing points in some of the traversed cells. Additionally, the trawl touches the bottom behind the vessel (~ 200 - 500m).

Data analyses

Data analyses were conducted in R (R Development Core Team, 2008). To find the relationship between fishing intensity and the effect of the sea bottom, we fitted linear models with fishing intensity as independent variable, and number of trawl marks and the abundance of sea-pens as a dependent variables, respectively. Models were fitted using VMS data only from *Nephrops* trawlers. From these statistical models we obtained the coefficient of determination (R^2) and the coefficients of intercept and slope.

Results

Video recordings to estimate the influence of trawl marks

There were 85 stations included in this study, resulting in 823 minutes of video material. Transect length varied between 115 m and 465 m. A total of 609 trawl marks of six different types and four different states were observed. The average number of trawl marks per 100 m² transect ranged from 0 to 13.5, with an average of 2.5 mark per stations (Figure 3). In total, 71 % of all video transects had at least one trawl mark.

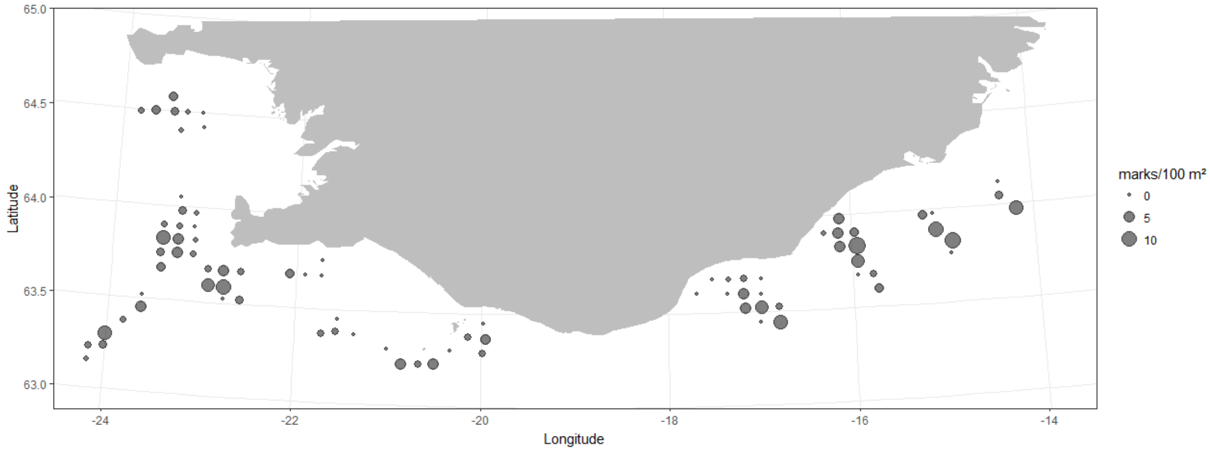

***Figure 3**. Number of trawl marks per 100 m² transect, from 2016 UWTV-survey.*

Trawl marks varied in abundance, depending on their type and state. Type A was the most common type (360 marks), trawl mark D the least common one (24 marks). State 3 was the most common, followed by state 1. There were 26 marks that could not be classified with certainty as caused by a trawl (state 4) and were excluded from further analyses.

Table 2. *Number of trawl marks classified into different types and states.*

Status	1	2	3	4	Sum
Type					
A	89	87	165	19	360
B	21	15	18	3	57
C	37	44	23	3	107
D	10	7	7	0	24
E	19	12	4	0	35
F	16	6	4	0	26
Sum	192	171	221	25	609

It was possible to estimate the depth of 132 mark. The deepest trawl mark was found in type A with a depth of 11.1 cm. This type had the largest variance in depth. Type D had the deepest average depth (5.2 cm). The average depth for all types was 3.8 cm (Figure 4). It was not possible to measure any depth for type E since only the surface was scraped and there was no actual furrow visible.

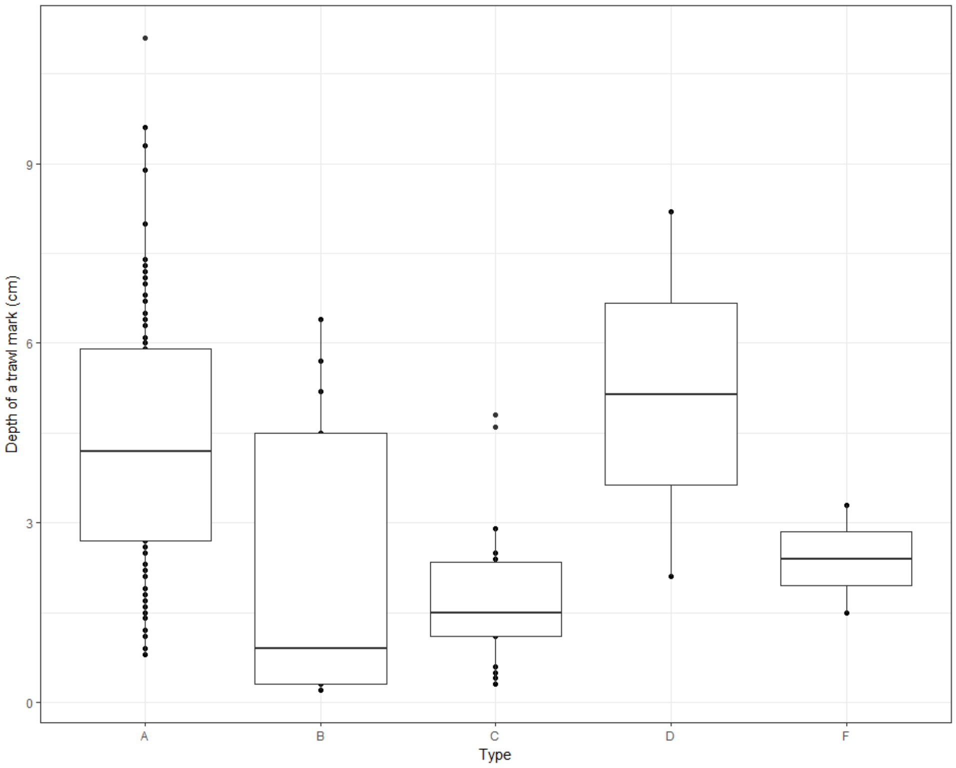

Figure 4. *Depth of the trawl marks differentiated into the different types. The boxes show the quartiles and mid-points of the data and whiskers the ranges of the data by 95% likelihood but dots outside whiskers are outliers.*

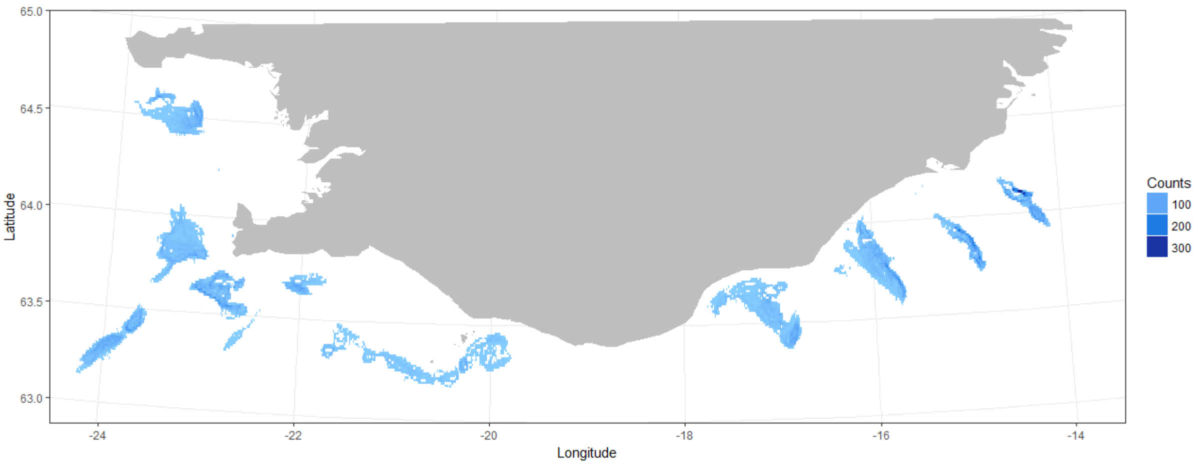

Figure 5. *Spatial distribution of VMS counting's since 2015; one count reflects a VMS data point in a 0.9 km² area, measured every 10 minutes.*

The fishing intensity as calculated from the VMS data was clustered around the *Nephrops* fishing grounds, with a maximum of 340 points per km². During the observed time, each cell within the fishing area was trawled on average 20.75 times. A total of 43.8% of the VMS records correspond to vessels using a single trawl, which had an average door spread of

60 - 65 meters. The remaining 56.2% records correspond to vessels fishing with two trawls combined with a weighted clump, with an average door spread of 120 - 130m. Consequently, the area was trawled on average 2.1 times between January 2015 and June 201.

The number of trawl marks per 100 m^2 correlated significantly with the number of VMS per cell from vessels fishing for *Nephrops* in this area, during 2015 and until the survey in June of 2016. The intercept of the linear model was 0.76 ($p = 0.033$) and the slope 0.07 ($p < 0.001$). In the model 36% of the observed variances was explained ($F = 46.12$, $df = 83$, $p < 0.001$). When adding also in data from the year 2014 the model explained 32 % ($F = 39.61$, $df = 83$, $p < 0.001$) of the observed variance and the intercept was 0.60 ($p = 0.121$) and the slope 0.04 ($p < 0.001$). Additionally, when using data only from the year 2016 we could explain 31% ($F = 36.46$, $df = 83$, $p < 0.001$) of the observed variance with intercept of 1.53 ($p <0 .001$) and slope of 0.15 ($p < 0.001$).

On average, 45.6 *Virgilaria mirabilis* sea pens were found per minute of video footage (Figure 6). The highest abundance per minute was 440 individuals, while at ten stations, there were no *Virgilaria* specimens at all. No significant correlation was found between the number of VMS records per cell from 2015 and until the survey in 2016 and the number of sea pens per minute ($F=1.56$, $df=83$, $p=0.21$), although the trend was negative. There was also a negative trend between the number of trawl marks and the numbers of sea pens visible, but again it was not statistically significant ($F=3.55$, $df = 83$, $p = 0.06$). However, when we excluded stations without *Virgilaria*, the trend was marginally significant ($F=4.62$, $df = 67$, $p = 0.035$), with only 6.4% of the observed variance explained. *Pennatula spp.* was observed less frequently with an average 1.3 individual per station. The highest average number per minute of video footage was 62.1. *Pennatula* was only present at 12 stations; therefore linear model was not obtained. However, stations with more than one specimen of *Pennatula* had fewer than three trawl marks (Figure 7).

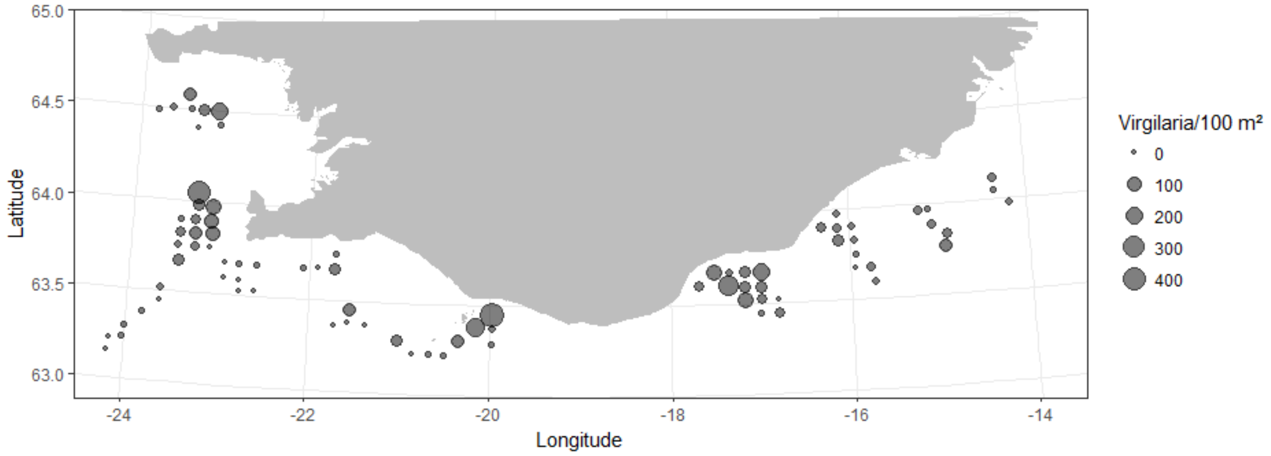

__Figure 6__. Number of Virgilaria sea pens counted over a distance of 100 m², from 2016 UWTV-survey.

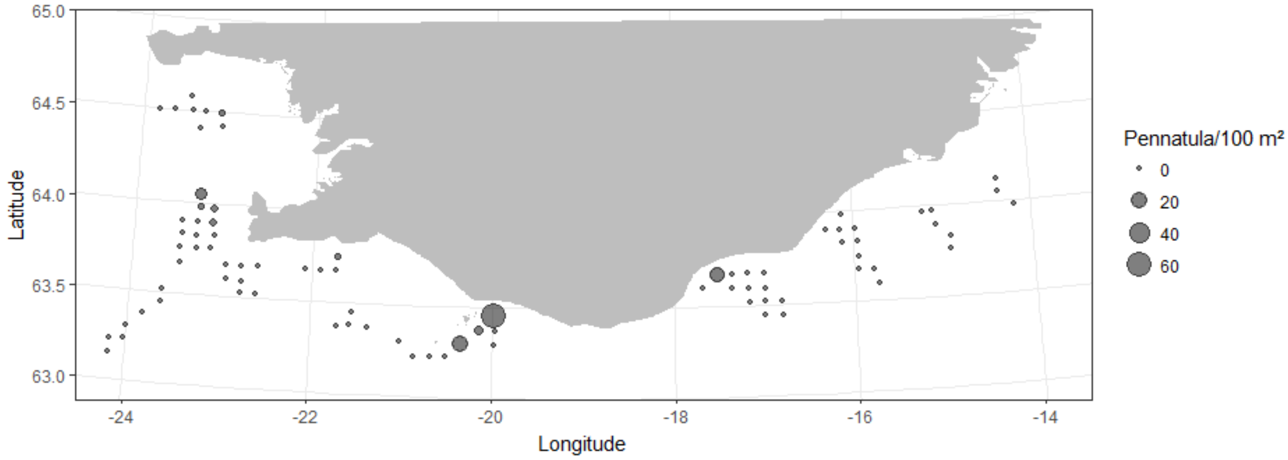

__Figure 7__. Number of Pennatula spp sea pens counted over a distance of 100 m², from 2016 UWTV-survey.

Discussion

In this study trawl marks were classified into five different types, which varied in abundance and depth. The trawl marks measured did not reach the depths of 20 - 30 cm as described by Krost et al. (1990). This might on the one hand be an effect of uncertainties in the measuring procedure, and on the other hand on a harder mud substrate. Krost et al. (1990) also suggested that deeper trawl marks result from jumping otter boards, triggered by bottom topography or course changes of the vessel.

Trawl marks were compared to the components of the *Nephrops* trawl and matched together when possible. However, depth varied considerably within types and some of the types could not be matched to a component of the gear assuredly with great certainty. Type A was the most common furrow and penetrated up to 11.1 cm deep into the bottom. Due to this observation and its shape, it is likely to be the mark of an otter board. Beside the furrow, these marks are also characterized by its hill next to it. These hills arise if the substrate is pushed aside by the otter boards. Otter boards are the heaviest part of the gear and are in steady contact with the substrate to keep the gear close to the bottom and to increase the catchability for *Nephrops*. The depth of types B and C was similar to each other with means of 2.2 and 1.8, respectively. While type B had a narrow shape, type C was wider. Both types could occur from an otter board which does not penetrate deeply. Type C could also result from the clump, the middle part between two *Nephrops* trawls. The two parallel furrows of type D penetrated deeply, having a greater average depth than type A. This could be the result of heavily weighted ground gear rolling or dragging over the bottom such as rockhoppers. Rockhoppers or bobbings are not usually used in the *Nephrops* fishery but rockhoppers are used in other demersal fisheries operating occasionally in the area. This mark only occurred 24 times suggesting of an uncommon fishing method in that area. Nevertheless, it could also show two marks of type A or B occurring close next to each other. Type E does not penetrate the bottom measurably, suggesting that they were caused by a light part of the gear. Due to its wavy and small-scale shape, this could be the result of a net, particularly if the codend sinks. This mark was only identified 35 times. Additionally, this could also be the mark of the wing part of rockhopper. Although this trawl mark does not penetrate the substrate deeply, benthic structures and animals can be harmed.

Satellite tracking data for vessels (VMS) enables a comparison of fishing activity with the abundance of trawl marks and benthic organisms, in this case, sea pens (Buhl-Mortensen et al., 2016). The fishing grounds resulting from the VMS data are identical to the ten grounds Eiríksson (1999) identified. That implies that this area has been heavily trawled for several years and as suspected there was a clear positive relationship with the VMS data and the number of trawl marks found on the ground. Since there was no reference experiment to obtain a pre-trawling comparison included in this study, it was difficult to estimate the age of each trawl mark. Several studies estimate the age of trawl marks on the muddy ground to last several months to few years (Northeast Region Essential Fish Habitat Steering Committee, 2002). We could explain most of the variance by using VMS data from the previous 18 months. Nevertheless, the linear regression showed a positive intercept of 0.76, which would mean that on average 0.76 furrows exist per 100 m^2 in an area without VMS data since 2015. Adding in data from the year 2014 lowered the intercept and further when using only data from 2016 we got higher intercept. This suggest that many of the trawl marks are older than six months and at least some of marks could be older than one and half year. There are suggestions from this survey that in heavily trawled area fewer sea pens are visible. However, the correlation is weak, and more data are needed, both on the distributional patterns of the sea pens and the cumulative intensity of trawling on the grounds. Overall, these models are explanatory and given more data more comprehensive analysis could be carried out.

Compared to the side-scan sonar technique, video transects only cover a small area. However, compared to Krost et al. (1990) it was possible to identify different types of trawl marks and also to classify them into different states. Nevertheless, it is critical to correctly place the video transects and their observed trawl marks into their corresponding cells. Additionally, only a fraction of each grid cells is actually covered by the video transects. Furthermore, the position of the vessel which is used for this analysis, is not the exact position of the sledge.

In conclusion, wide areas of the *Nephrops* fishing grounds are in contact with fishing gear several times every year. The sea bottom gets into contact with the otter boards, ground gear, clumps and the net, varying in penetration depth. These contacts cause trawl marks which are likely to affect the benthic fauna. To understand how these different components influence the bottom, it is important to have reference areas without trawling as a comparison. At the same time is important to seek better fishing techniques with less direct contact to the bottom.

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