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Gear performance and catch process of a commercial Danish anchor seine

Thomas Noack^{a*}, Daniel Stepputtis^b, Niels Madsen^{a,1}, Kai Wieland^a, Stefanie Haase^b, Ludvig Ahm Krag^a

^aTechnical University of Denmark, National Institute of Aquatic Resources, North Sea Science Park, PO Box 101, DK-9850 Hirtshals, Denmark; tel: +45 35 88 32 51; fax: +45 35 88 32; email: thno@aqua.dtu.dk

^bThünen Institute of Baltic Sea Fisheries, Alter Hafen Süd 2, 18069 Rostock, Germany

*Corresponding author; email: thno@aqua.dtu.dk

¹Current affiliation: Section of Biology and Environmental Science, Department of Chemistry and Bioscience, Aalborg University, Fredrik Bajers Vej 7, 9220 Aalborg, Denmark

Abstract

The Danish anchor seine is an efficient type of active fishing gear used globally. Knowledge of the gear and its operational performance is limited, but needed to ensure efficient fishing and appropriate management. During this study, a combination of GPS loggers, depth loggers, and cameras, were utilized to collect quantitative information about the geometry of the seine net and seine ropes during all stages of the fishing process, and to identify when fish enter the seine net. Measurements of the horizontal and vertical openings of the seine net indicated that gear geometry changed continuously during the fishing process. Underwater recordings from the net revealed that the majority of fish entered the seine net within the last quarter of the fishing period, and that fishermen are able to control the timing of increasing the retrieval speed to prevent losing fish late in the fishing process. Underwater recordings of the seine rope provided qualitative results indicating that interactions with the sea bed are relatively minor in nature.

Keywords

Demersal fishery, Fish behavior, Fishing gear geometry, Selectivity, Swept area

1. Introduction

The majority of commercial fishing activity in European waters is conducted using a few different passive and active fishing methods (Gabriel et al., 2005). The choice of fishing method depends on factors such as target species, vessel size, available quotas, and the flexibility and efficiency of the specific gear. A thorough operational knowledge and understanding of the particular gear is required by fishermen (e.g., to maximize catch efficiency and quality of the product) (Tietze et al., 2005) and managers legislating their use in different areas and fisheries (e.g., for Marine Spatial Planning purposes). Extensive theoretical and experimental studies have been conducted to describe and quantify the catch process, including the gear's interaction with the seabed during the catch operation for fishing gears like trawls, gillnets, and pots (see Dayton et al. (1995) and Kaiser et al. (2003) for reviews).

In contrast to demersal trawling, there is little knowledge available for the Danish anchor seine (DAS), in particular, data regarding its operational performance is limited and almost non-existent. The DAS is an active demersal fishing gear, used worldwide in different commercial fisheries. Under European legislation, the DAS belongs to the same legislative category as demersal trawls (Council Regulation (EC) 850/98), despite the fact that fishing operations between both gears differ considerably, resulting in differences in selectivity (Herrmann et al., 2016b; Noack et al., 2017), energy efficiency (Thrane, 2004), and quality of the caught fish (Dreyer et al., 2008; Suuronen et al., 2012). In contrast to the more fixed and stable geometry of the towing-rig in demersal trawls, the gear-geometry of the DAS is continuously changing throughout the fishing process. The fishing process of a DAS can be divided into three main phases: i) the setting phase (Fig. 1A–C), ii) the herding phase (Fig. 1D–E), and iii) the catching phase (Fig. 1F). When approaching the fishing location, the process begins by dropping an anchor. Attached to the anchor is a set of marker buoys and one end of the first lead-filled seine rope, which is subsequently laid out (Fig. 1A). After setting the seine net, which is attached to the other end of the first rope (Fig. 1B), the second rope is laid out (Fig. 1C). As soon as the seine ropes and seine net are laid out, the vessel returns to the anchor buoys (Fig. 1D), picks up the first end of the first rope and begins hauling the seine ropes. The hauling speed of the seine ropes gradually increases during the haul-

back operation, herding fish into the path of the approaching seine net, while the area enclosed by the seine ropes gradually shrinks (Fig, 1E). Instead of a symmetrical lay-out pattern, the ropes are often laid out asymmetrically by towing the end of the second rope back to the anchor buoy (Fig. 1C). This is termed “towing on the rope,” and is common practice in Denmark as it increases the fished area. In this case, the area starts to get smaller at the moment the second rope is paid out and the vessel starts towing it back to the anchor buoy. Another method of demersal seining is called Scottish seining (Fly-shooting, Fly-dragging). Because Scottish seiners do not use an anchor and the vessel moves forward during the retrieval phase, Scottish seining can be regarded a hybrid between anchor seining and demersal otter trawling (Eigaard et al., 2016). Scottish seining is often conducted by larger vessels using larger gear (i.e., larger seine nets and thicker seine ropes), in comparison to Danish seining.

Although assumptions have been made about how DASs operate during fishing (Eigaard et al., 2016), how they interact with the marine environment (Suuronen et al., 2012; Eigaard et al., 2016) and on the quality of the catch (Dreyer et al., 2008; Suuronen et al., 2012), quantitative studies are lacking. There is no clear description of how the seine ropes and the seine net operate during the fishing process, what part of the encircled fishing area is covered by the seine ropes and the seine net, when fish actually enter the seine net during the fishing process, and how the gear geometry changes during the fishing process. Due to operational differences between standard demersal trawls and DASs, acoustic sensors, commonly used in demersal trawl fisheries to monitor gear geometry, are unable to provide the detailed information routinely collected for demersal trawls. These operational differences and the absence of monitoring alternatives are the likely reasons for the lack of operational quantifications of the DAS process.

In the current study, simple methods and tools were developed and applied to establish a detailed understanding of the DAS fishing operation. This study aimed to describe the lay-out pattern of the seine ropes, the movements of the seine ropes, and the dynamics of seine net geometry during the entire fishing operation using GPS loggers and depth sensors. In addition, underwater cameras were used to identify

the point at which fish actually enter the seine net and to record how the seine ropes move over the seabed.

2. Materials and Methods

2.1. Study site and gear specifications

The Danish seining experiments were carried out on board the commercial Danish seiner S15, *Vera Marie*, (overall length: 16.1 m, engine power: 140 kW) in shallow waters (<10 m) in the Kattegat (ICES area IIIaS; Fig. 2) during August 2015. The vessel's own seine net, with 360 meshes around the fishing circle (nominal mesh size: 120 mm), and a ground rope (Taifun wire, diameter: 14 mm, weight in air: 0.25 kg·m⁻¹, weight in water: 0.15 kg·m⁻¹) of 43.6 m in length were used. The ground rope was weighted by lead (total lead weight: 90 kg). For protection, the weighted ground rope was wrapped with 16 mm rope made from coconut fibres (weight in air: 0.2 kg·m⁻¹, weight in water: neutral). The commercial codend used was made of PET 4 mm double twine (inner mesh size: 120.2 ± 2.7 mm SD, N = 40, measured with an OMEGA gauge (Fonteyne et al., 2007)) with 97 open meshes in circumference, following commercial practice. The vessel used two sets of 15 coils (~220 m each, producing two sets of ~3,300 m each) of leaded seine ropes ("Icelandic seine rope", diameter: 26 mm, weight in air: 0.56 kg·m⁻¹, weight in water: 0.12 kg·m⁻¹). The seine ropes were hauled back to the vessel using hydraulic rope reels (Kynde & Toft Thyborøn, Denmark). Retrieval of the seine ropes was done in a four step process, where the first seven coils were retrieved at ~1.0 kn (~0.5 m·s⁻¹) and the following four coils at ~1.5 kn (~0.8 m·s⁻¹). Coils 12 and 13 were retrieved at ~2.0 kn (~1.0 m·s⁻¹) and the last two coils at ~2.5 kn (~1.3 m·s⁻¹). Retrieval speed was estimated by dividing the length of one coil (220 m) by the time it took to retrieve it. These times were noted down for hauls 4-7.

2.2. Experimental setup

During all hauls, one GPS logger (Canmore G-PORTER GP-102+; accuracy: 2.5 m circular error probability) was used on board S15 to track the vessel. Eight additional loggers were attached to

the gear at different positions to track the movements and geometry of the seine ropes and seine net during the fishing process (Fig. 3). Each GPS logger provided a position (latitude and longitude) every second. The GPS loggers were connected to the gear using a surface connection system (SCS, Fig. 4A) specifically developed for this study, which kept the GPS logger above the water surface close to the point of interest of the seine net or seine rope. The SCS was constructed of a 10 m dog leash with a retraction mechanism (flexi Giant Professional) and a diving buoy with an inner compartment (Mares Apnea; buoyancy: approximately 8 kg) containing a waterproof box (Subgear Mini Dry) with the GPS logger inside. Two SCSs were attached to both wing ends of the net using a snap hook. Three more SCSs were equally distributed along each seine rope using a shackle to allow rotation of the seine rope without becoming entangled with the SCS. To prevent the mechanisms from slipping along the seine rope, two metal rings were attached to the seine rope at each position (Fig. 4A). The length of the dog leashes was the reason for the limitations in water depth.

Intercalibrated data storage tags, measuring salinity, temperature, and depth (Star-Oddi CTD; depth accuracy: $\pm 0.6\%$), were mounted at the centre of the headline and the ground rope of the seine net (Fig. 3). The loggers recorded depth every second, allowing the vertical opening of the net mouth (headline height) to be calculated.

To investigate at what point during the fishing process fish entered the seine net, five time-synchronized underwater video cameras (GoPro, Inc. HERO 3+) were attached to the seine net. Three cameras were attached to the headline, one in the centre and one on each wing, with all three facing forward. Two additional cameras, one facing forward and one facing backward were mounted inside the codend. The video recordings also provided information about the behaviour of the seine net during the fishing process. Two additional cameras were used to monitor the ropes moving over the seabed. These cameras were attached to novel observation platforms created during the study, which maintained their positions on the seabed whilst allowing the seine ropes to pass underneath (Fig. 4B). These were made by filling half a trawl float ($\varnothing = 30$ cm) with concrete, with a steel pole for the camera attachment mounted into the middle and attaching a marker buoy to the pole by a rope. Following directions from

the skipper, the observation platforms were set out prior to fishing in locations where the seine ropes, but not the seine net was expected to pass by.

The timing of key events during the fishing process was recorded for each haul (start: pay out first rope (Fig. 1A), shoot: set seine net (Fig. 1B), end rope 2: start towing gear back to the anchor (Fig. 1C), anchor: moor to anchor (Fig. 1D), end: gear is retrieved). Further information recorded during each haul included sea state (following the protocol of Wileman et al. (1996)) and total catch weight. All experimental fishing operations followed commercial fishing practice as closely as possible. Commercial fishing depths of Danish seiners in the Kattegat and Skagerrak are in a range from <10 m up to approximately 100 m.

2.3. Data analysis

The combination of time synchronized positions from all GPS loggers provided the basis for visualizing the performance of the seine net and ropes throughout the fishing process. The positions delivered by individual GPS loggers showed their specific position during the fishing operation. The simplified geometry of the seine ropes was estimated using linear interpolation between the point estimates of the loggers. "Polynomial approximation with exponential kernel" smoothing (Bodansky et al., 2002) was used at the point estimates to reduce the sharpness of the edges. In situations where a GPS logger became submerged and was unable to receive GPS signals, the missing data were estimated as interpolated values using the positions before and after submersion. Changes in wing spread (horizontal opening) during the fishing process were estimated by calculating the distance between the GPS loggers at the wing tips of the seine net. The difference between the depth loggers on the headline and the ground rope was calculated to obtain the headline height. Total area swept was estimated as the size of the area that had been encircled by the vessel when laying out the gear and average area swept hourly was calculated as total area swept divided by haul duration. The area swept by the seine net itself was estimated as the size of the area covered between the two GPS-loggers at the wings of the seine net, i.e., GPS 4 and GPS 5. Animations of the fishing process were created using ArcGis software.

3. Results

3.1. Haul overview

Seven valid hauls ranging in duration from 3 hours and 11 minutes to 4 hours and 28 minutes were conducted (Table 1). Depths ranged from seven to ten meters. Total catches were variable and ranged from 34–800 kg. The majority of the catch was composed of plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*). The crew quickly became familiar with attaching and detaching the SCSs, resulting in only short retrieval stops for equipment handling during setting and retrieval of the gear. Only 0.04–0.06 km² were swept by the seine net itself and thus, by the ground rope (Table 1). The total area swept by the whole gear varied from 4.17–5.51 km² and the average area swept hourly ranged from 1.07–1.57 km² (Table 1). Differences in the layout patterns of the seine ropes, and also in the “towing on the rope” phase (Fig. 1D) lead to differences in haul durations and swept areas. Both would normally increase with an extended “towing on the rope” phase. However, this relationship could not be seen consistently within the present study (Table 1) which was likely caused by the handling times of scientific equipment that is not used in commercial hauls.

3.2. Sensor measurements and camera observations

Although layout patterns of the individual hauls show some variance (Fig. 2), gear performance followed a general pattern. Therefore, results about gear behaviour are only shown for the hauls with the highest resolution, i.e., haul 5 during which the majority of GPS loggers stayed at the surface for most of the fishing process and haul 7, which had the most additional sensors and cameras working throughout the fishing process. Haul animations of both hauls including detailed information obtained by sensors and cameras can be found in the supplementary material S1 and S2. Analysis of the GPS logger data showed that the initial lay-out pattern of the two seine ropes was not symmetrical (Fig. 5, supplementary material S1 and S2). It also demonstrated that the seine net did not pass the centre of the fished area in a straight line.

A maximum wing spread of around 30 m was reached shortly after setting the seine net before it actually started moving (Fig. 6). Headline height was approximately 8 m at this time. Vertical spreading of the seine was not affected by the shallow fishing location as indicated by the depth logger attached to the headline, as it remained submerged after the seine net was set. As soon as the vessel started towing on the rope, the entire second rope started moving and also the net began to move at a speed of less than 1 kn ($\sim 0.5 \text{ m} \cdot \text{s}^{-1}$; Fig. 6, supplementary material S1 and S2). This represents the moment when herding of the fish began. Since the seine net was dragged only on the second rope during this phase, it was dragged sideward and remained in an overspread state (supplementary material S1 and S2), i.e. the distance between the wings was higher than when the net is actually fishing. Thereby, also the part of the first rope closest to the seine net started to move slowly by being dragged by the second rope (supplementary material S1 and S2). Only when the first rope was picked up and both ropes started to be retrieved did the first rope start to move as a whole with similar speeds as the second rope ($\sim 1 \text{ kn}$) and the geometry of the seine net began to change. At this point, the shape of both ropes became more symmetric and the seine net began moving forward and more directly towards the vessel, indicating a better symmetry of the net, which is necessary in order to allow the fish to enter. Headline height decreased to $\sim 2 \text{ m}$ and subsequently increased as fishing progressed, reaching values of $< 3 \text{ m}$ when the first fish swam into the net and $> 4 \text{ m}$ when the majority entered (Fig. 6 and Fig. 7). Wing spread decreased over the process to approximately 25 m when the first fish were observed entering the seine net and to less than 15 m when the majority of fish entered (Fig. 6 and Fig. 7). The main species observed were flatfish such as plaice and flounder, but roundfish species including red gurnard (*Chelidonichthys lucernus*) and greater weever (*Trachinus draco*) were also recorded. Cameras inside the gear showed that for all hauls, the majority of fish entered the seine net within the last quarter of the haul (Table 1, supplementary material S1 and S2). Prior to the ropes becoming in close proximity with one another, fish swam in front of them, but as soon as the rope of the opposite side appeared on the fish's escape route, it changed escape strategy. Either it swam into the direction of the seine net or away from it. Catching the fish swimming away from it was ensured by the previously mentioned stepwise increases

in retrieval speed and corresponding net speed, reaching values of nearly 2 kn ($\sim 1.0 \text{ m}\cdot\text{s}^{-1}$) at the time when most fish swam into the net (Fig. 6). Fish stopped entering the net when the wing spread was ~ 10 m, recorded as the moment when the ground rope lifted off the sea floor. Towards the end of the fishing process, wing spread decreased to less than 5 m (Fig. 6). Headline height increased to ~ 8 m and retrieval speed increased to its final step, resulting in a net speed of up to ~ 2.5 kn ($\sim 1.3 \text{ m}\cdot\text{s}^{-1}$; Fig. 6). Abrupt jumps and peaks in the curves of wing spread, headline height, and net speed were caused by stopping the retrieval process in order to detach the SCSs from the seine ropes.

The recordings of the cameras mounted to the observation platforms showed fish being herded by the seine ropes and indicated that, except for slight smoothing effects, no pronounced changes in the sea floor were visible after the seine ropes passed by (Fig. 8). Dust clouds caused by the seine ropes were not visible any longer after two minutes.

4. Discussion

Using relatively simple methodologies, we were able to obtain a detailed description of the overall performance of a DAS during all stages of the fishing process. We established quantitative information about the geometry of the seine net as well as the seine ropes and identified when fish entered the net. The results revealed that the seine net changed shape considerably during the fishing process and that the majority of the fish entered the seine net late in the fishing process, in any case less than 65 minutes before the seine net was retrieved.

The experiments within this study were restricted to water depths < 10 m and it might be speculated that the seine net performs differently when fishing in deeper areas. Fishermen do, however, follow the same procedures independent of depth, which indicates that fishermen assume gear geometry patterns to be similar in deeper waters. Temporary stops in the retrieval of the seine ropes were necessary in order to detach the SCSs from the seine ropes. Those occasional stops caused the sudden jumps in individual values of GPS tracks, wing spread curves, and headline height curves, but occur during commercial seining as well (e.g., to remove entangled seaweed). Therefore, the general documented

pattern can be regarded as reflecting normal commercial conditions. The linear interpolation used between the GPS positions along the seine ropes does not reflect the true geometry of the seine rope, but gives a good, clear resolution of seine rope movement during the fishing process. Such point estimates of different gear parts during different stages of the fishing process provide an overall understanding of the fishing operation of the DAS and are valuable for developing and calibrating theoretical simulations of similar processes in other studies such as Madsen et al. (2017).

The underwater observations showed that most fish entered the seine net in the last quarter of the fishing process (33-63 minutes before the seine net was retrieved). In contrast to trawling, fish spend a larger portion of the fishing process swimming in front of the comparatively slow moving seine ropes (supplementary material S1 and S2) and only spend the last period of the haul either in front of or inside the net. Only this part of the seining process is similar to trawling. Late entry has also been observed for Scottish seines (Herrmann et al., 2016a) and is of interest in three respects. First, it is likely the reason for the high quality of DAS catches (Dreyer et al., 2008; Suuronen et al., 2012), as the exhaustive period in front of or inside the seine net, and thus the chance to suffer from damages by contact to the netting or other parts of the catch, is limited for most fish. Secondly, this reduced risk of injury could positively affect discard survival. Therefore, experiments investigating discard survival for DAS should be encouraged as they would allow for a comparison to the existing trawl studies (e.g. Methling et al., 2017; Morfin et al., 2017) and further provide knowledge required by managers in terms of the landing obligation (Council Regulations [EU] 1380/2013 and 2016/72). Finally, the late entry of fish is interesting from a selectivity point of view as DASs and bottom trawls belong to the same legislative category, and the same selective devices can be used in both fisheries. However, to ensure that these selective devices work for both gears, they need to be equally efficient during both the short intense catching period for DAS, as well as during the gradual catch accumulation observed for demersal trawlers. Although codend selectivity of DAS has been investigated in previous studies (Herrmann et al., 2016b; Noack et al., 2017), future studies should investigate the efficiency of mandatory selective devices in high entrance seine fisheries like DAS.

251 Generally, the majority of fish herded were observed to enter the codend just before the ground
252 rope lifted off the seabed. This indicates that the fishermen's procedure of setting the gear and increasing
253 winch speed in specific steps throughout the fishing process works quite well, despite the absence of
254 equipment to monitor the seine net, seine ropes, and fish entry to inform the process. For one haul,
255 however, most fish entered the codend after the ground rope lifted off the seabed, i.e. parts of the herded
256 catch were likely lost as fish could have swum beneath the ground rope. This shows that small operational
257 differences during this short and intense catching period of the seining process could result in an early
258 lift of the net off the seabed, which could lead to large catch losses.

259 Video footage from the well-functioning observation platforms showed the seine ropes sweeping
260 the seabed during the herding phase and support the assumptions of previous studies which predicted the
261 effects of DAS on the seabed to be minor (ICES, 2006; Suuronen et al., 2012). The quantitative
262 description of the seining process showed that the theoretical estimates of the area swept by the seine net
263 were higher than empirical estimates from the current study (Eigaard et al., 2016: ~10%; current study:
264 ~1%). The impacts of DASs on the seabed hypothesized in Eigaard et al. (2016) may therefore be an
265 overestimate, especially as the majority of seabed impact is expected to be caused by the ground gear of
266 the seine net (Eigaard et al., 2016), which is of heavier construction than the seine ropes are. Since no
267 studies exist which actually quantify those effects, future studies should aim to quantify the seabed
268 impacts from different components of the DASs; particularly the ground gear, but also by the seine ropes
269 as they sweep the majority of the total fished area during the fishing process. A tool that could be applied
270 in such studies is the observation platform invented within study, e.g. to attach cameras or different
271 sensors to. Some countries already consider DAS and Scottish seines to have a lower environmental
272 impact than demersal trawling and give demersal seiners exclusive access rights to more sensitive areas
273 (e.g. in Norway, Regulations governing the sea-fishing activities J-125-2016 §15, §53; Norwegian
274 Directorate of Fisheries) or intend to do so (e.g., the Netherlands (IenM and EZ, 2012)).

5. Supplementary material

The online supplementary materials S1 and S2 provide haul animations for hauls 5 and 7. The animations include a time stamp and information about wing spread, headline height, and observations of fish (“Fish in front of gear,” “Fish in codend” and “Codend full of fish”).

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Table 1. Overview of hauls conducted during the study. Depths were extracted from the depth logger attached to the ground rope. Sea state was recorded following Wileman et al. (1996). Duration refers to the time from the start of the fishing process (laying out the first rope) until the time when the gear was fully retrieved. Total swept area (size of area encircled by vessel), area swept by the seine net (size of area covered between the two GPS-loggers at the wings), average area swept per hour (total swept area/duration), and additional haul-specific information are given.

Haul	Date	Depth range (m)	Sea state	Duration (h:min)	Total catch (kg)	Area swept (km ²) total / by seine net	Average area swept hourly (km ² ·h ⁻¹)	Time when majority of fish was observed in codend (h:min)	Remarks
1	11.08	NA	2	4:26	800	NA / NA	NA	03:23	could not be used for gear performance analyses due to problems with GPS-loggers
2	13.08	NA	2	4:25	150	4.72 / 0.06	1.07	03:24	-
3	13.08	NA	1	3:17	390	4.17 / 0.06	1.27	02:27	GPS 2 moved 220 m along the rope to the next splicing
4	21.08	8-10	1	4:28	49	5.51 / NA	1.23	NA	lost GPS 4; several additional stops to remove algae during haulback
5	21.08	8-10	1	3:11	34	5.00 / NA	1.57	02:38	GPS 5 centred; several additional stops to remove algae during haulback
6	22.08	7-10	2	3:44	34	4.42 / 0.04	1.18	NA	several additional stops to remove algae during haulback
7	22.08	8-10	2	3:22	158	4.82 / 0.05	1.43	02:43	-

356

357 Fig. 1. The three main phases of the fishing process of a Danish anchor seine: i) the setting phase (A–
 358 C), ii) the herding phase (D, E), and iii) the catching phase (F).

Fig. 2. Study area and vessel tracks for the seven hauls conducted on board the Danish seiner S15, *Vera-Marie*, in 2015.

Fig. 3. Locations of GPS loggers on ropes and the seine net, and a close-up of the seine net indicating the locations of GPS loggers, data storage tags (DST), and tension sensors. Note: Rope one is turned around after each haul, so the relative position of GPS 2 changed after each haul.

Fig. 4. Experimental tools. A: Surface connection system (SCS). B: Observation platform.

Fig. 5. GPS movements and simplified presentation of rope movement from haul 5 over time after beginning of fishing process (hour:minutes). The dashed line represents the vessel path. V is the current position of the vessel and the numbers denote respective GPS loggers on seine ropes (1,2,3,6,7,8) and the seine net (5). Background colours indicate phases (white: setting phase, light grey: collecting phase, dark grey: catching phase). Note: GPS 4 could not be used in this haul and GPS 5 was moved to the centre of the headline.

Fig. 6. Parameters describing the performance of the Danish anchor seine (wing spread, headline height, and net speed) for haul 7, including time information about fishing process (hour:minutes) and fish observations.

380

381 Fig. 7. Fish entering the codend in haul 1. A: The first fish entered the codend (early herding phase; after
382 2:56 hours, 66% of the fishing process). B: Few fish in the codend (early herding phase; after 2:59 hours,
383 67% of the fishing process). C: Majority of fish entered the codend (catching phase; after 3:23 hours,
384 76% of the fishing process).

385

386 Fig. 8. Interactions of the seine rope with the sea floor with white circle indicating the same spot just
387 before rope passes by (A), when rope passes by (B) and one minute after rope passed by (C).