A comparison of abundance, distribution and behavior of Northeast Atlantic mackerel (*Scomber scombrus* L.) during curved and straight forward trawling.

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Master of Science in Fisheries Biology and Management

By

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ABSTRACT

Northeast Atlantic Mackerel (*Scomber scombrus*) is one of the largest and economically most valuable fish stocks in the world. However, due to a large area of distribution, low acoustic backscatter and highly dynamic and migratory behaviour between several Exclusive Economic Zones (EEZs), reliable abundance estimation and fish stock assessment are difficult and include a large level of uncertainty. In order to reduce uncertainties in the mackerel stock abundance estimates, a new pelagic trawl methodology and standardized swept-area surveys for mackerel abundance estimation was established in 2011. The new method included development of a new surface trawling method and a new trawl, the multipurpose pelagic ecosystem trawl (Multpelt 832). However, various uncertainty is still linked to the new trawl methodology. This thesis uses Deep Vision images, GoPro videos and total catch data from a methodological cruise conducted in June 2015 as well as catch data from the 2015 International Ecosystem Summer Survey in the Nordic Seas (IESSNS) in order to investigate the demanding curved trawl method used in the IESSNS survey today. The analyses conducted show that the curved trawling method did not have significantly different catch rates or length distribution compared to less demanding straight forward trawling. Consequently, a change of the trawling method used in the IESSNS survey from a curved to a straight forward trawling procedure is recommended in order to simplify trawling. Furthermore, analyses of mackerel distribution during the methodological survey indicate small shoaling and loosely aggregating behaviour within individual hauls. Patchiness rarely led to only a single or few aggregations being encountered over the course of 30-minute-long hauls, supporting the use of a swept area survey for mackerel in this location and time. The swept area method in the IESSNS survey therefore seems to be a reliable and consistent method for abundance estimation of NEA mackerel.

CONTENTS

1. INTRODUCTION

1.1 ASSESSMENT OF FISH STOCKS IN NORTHEAST ATLANTIC WATERS

Numerous widely distributed fish stocks in the Northeast Atlantic and in Norwegian waters, such as Northeast Atlantic (NEA) mackerel (*Scomber scombrus*) and Norwegian Spring Spawning (NSS) herring (*Claupea harengus* L.) are advised through the International Council for the Exploration of the Sea (ICES), and management decisions are made by the different coastal states within the Northeast Atlantic Fishery Commission (NEAFC). The fisheries management in Norway is based on stock assessment plans that estimate the long-term impacts of different management plans on fish abundance, state of the stock and exploitation level (ICES, 2015). Norway shares most of its large pelagic fish stocks with other countries due to their highly migratory and widely distributed behavior. This leads to pronounced international research collaboration on e.g. NSS herring and NEA mackerel. For the majority of NEA fish stocks both fisheries dependent (data collected during commercial fishing) and fisheries independent (scientific survey data) data are used for the assessment (Gunderson, 1993). However, both methods are susceptible to possible biases and uncertainties. Fisheries dependent data rely heavily on the correct catch reporting of commercial fishermen and the allocation of their fishing effort (Gunderson, 1993; Cook, 1997; Maunder and Punt, 2004). This is especially true for pelagic schooling species, due to concentration of fishing effort limited in areas with high densities of fish schools, size selectivity of fishing gear and increased fishing efficiency over time (technological creep) (Fréon et al., 1993; Maunder and Punt, 2004; Hentati-Sundberg et al., 2014). Fishery independent data are expensive and time consuming to collect (Fréon et al., 1993; Gunderson, 1993) and often have some inconsistencies in survey practices (gear, survey dates, weather conditions, etc.), gear and vessel avoidance and only partly covering the fish stock's entire distribution area (Mesnil et al., 2009). In order to overcome possible biases and uncertainties of both methods, assessments often use a combination of fishery dependent and fishery independent data.

In order to be able to evaluate potential challenges regarding the assessment of fish stocks, it is important to consider and provide insight into the species' biology and behaviour. A possible way to go, is applying underwater camera technology, which has improved a lot during the last few decades (Graham et al., 2004) and offers several advantages over traditional capture-based fishery independent sampling. There are different kinds of underwater camera technology available, but some of the most suitable are Cam-Trawl (Williams et al., 2010) and Deep Vision (DV, (Rosen et al., 2013)), which are stereo camera systems specially developed for optical underwater observations inside fishing trawls. These camera systems, along with cheaper GoPro cameras (GoPro Inc, San Mateo, USA) are starting to work their way into assessment surveys, and gives the opportunity to collect high resolution data that can be applied to questions such as efficiency in different trawling methods and fine-scale fish distribution thorough the ocean.

1.2 NORTHEAST ATLANTIC (NEA) MACKEREL

NEA mackerel is a fast swimming, widely distributed, highly migratory pelagic fish species (Hamre, 1980; Trenkel et al., 2014). Mackerel play a key ecological role in oceanic and coastal ecosystems and now support one of the most valuable commercial fisheries in the North Atlantic (Jansen et al., 2014; Trenkel et al., 2014). The total catches of NEA mackerel reached 1.4 million tonnes in 2014 (ICES, 2015), and the 2015 export value of mackerel in Norway, was a staggering 450 million EUR (4.1 billion NOK) in 2014 and 410 million EUR (3.8 billion NOK) in 2015 (Aandahl and Johnsen, 2016). The population has rapidly increased in abundance and expanded its geographic distribution during the last decade (Nøttestad et al., 2015) and has recently been recorded as far north as Svalbard during extensive northward feeding migrations (Berge et al., 2015; Nøttestad et al., 2015).

It is challenging to perform good and reliable fish stock assessment, especially with species such as NEA mackerel, which have a very large distribution area and migrate between several Economic Exclusive Zones (EEZ's). This often leads to political and economic disagreement between nations, and scientific cooperation on an international level is needed to work it out (ICES, 2014b; Nøttestad et al., 2016b). Acoustic surveys for NEA mackerel are difficult due to low levels of acoustic backscatter (mackerel lack a of swim bladder), high density shoals which can lead to acoustic shadowing (except for loose aggregations during the feeding season) and distributions high in the water column (Nøttestad et al., 2016a) which can be above the surface acoustic dead zone (Korneliussen, 2010; MacLennan and Simmonds, 2013) and are very close to the vessel where avoidance is likely to be strongest (Slotte et al., 2007).

1.3 SURVEYS OF NORTH EAST ATLANTIC MACKEREL

NEA mackerel have had a rapid geographic expansion into northern and western parts of the Nordic seas during the last decade (Berge et al., 2015; Nøttestad et al., 2016b), and only a small amount of reliable fisheries independent data are presently used in the stock assessment (ICES, 2014b). The fishery-independent data collected earlier was a spawning stock biomass index from the triennial international mackerel egg survey (ICES, 2015) and a Norwegian tag recapture study run since 1968 (Tenningen et al., 2011). Since fishing quotas for mackerel are set on an annual basis, the egg survey conducted only every three years has been far from an optimal solution for such a valuable fish stock. Furthermore, egg surveys do not provide data on the age distribution in the stock (Gunderson, 1993) or uncertainty estimates (Nøttestad et al., 2016b). Data on tag and recapture from 1980 to 2006 is included in the assessment for NEA mackerel in ICES (ICES, 2014a). However, the tag and recapture data is partly fishery dependent, since the recapture is done by commercial fishermen, and as with most tag and recapture programs, the majority of tagged fish are never recovered. A new radio-frequency identification tagging method (RFID) was introduced in 2011 and will be evaluated at the next intermediate benchmark in 2017 (ICES, 2015).

In order to reduce uncertainty about the size of the stock ICES encouraged and requested establishment of a new pelagic trawl methodology for mackerel abundance estimation and assessment purposes in 2010 (ICES, 2013; ICES, 2014b; ICES, 2015). A new surface trawling method and a trawl called multipurpose pelagic ecosystem trawl (Multpelt 832), were developed. The new survey was called the International Ecosystem Summer Survey in the Nordic Seas (IESSNS) and uses the swept area principle with a pelagic trawl which is similar to the demersal swept area trawl sampling used on different demersal stocks (Nøttestad et al., 2012; ICES, 2013; Nøttestad et al., 2016b). The swept area principle is based on apportioning the total catch amount over a known area trawled with constant trawl opening and trawl efficiency, and can be expressed by the following equation (Kotwicki et al., 2011).

$$\frac{Catch\ (Kg)}{Area\ sampled\ (Km^2)} * X_{Trawl\ efficiency} = \text{swept area index (kg/km2).}$$

Adult mackerel is the main target species and the survey is limited to a five week period from July to August each year, when mackerel is believed to be distributed in the upper parts of the water column, feeding on zooplankton and other prey organisms near the surface (Langøy et al., 2012; Bachiller et al., 2016; Nøttestad et al., 2016a). The survey has been conducted since 2012 by Norway, Iceland and the Faroe islands, using four vessels to simultaneously cover the entire North Atlantic between 60°N and 73°N from Greenland to Norway. The survey is coordinated in space and time and all vessels use the same trawl construction and rigging and standardized trawling speed, time, etc. (Nøttestad et al., 2011; Nøttestad et al., 2012; Nøttestad et al., 2013; Nøttestad et al., 2015; Nøttestad et al., 2016b). Acoustic data are also collected from multifrequency echosounder and multibeam sonars during the survey (see Nøttestad et al. 2015), but are not included directly for stock assessment purposes for mackerel.

The IESSNS survey provides data on distribution, abundance, migration, ecology and aggregation of NEA mackerel (Nøttestad et al., 2016a; Nøttestad et al., 2016b). The results go through an ICES benchmark process before it is accepted and are put into a model with other kinds of survey data including the Norwegian tag recapture studies, egg and larval survey and an international bottom trawl survey (IBTS) which gives an recruitment index (ICES, 2014b). The final assessment is done through a state-space assessment model (SAM), which also uses fishery dependent data including catch at age and abundance index (ICES, 2014b; ICES, 2015).

There is, however, some uncertainty surrounding the IESSNS survey's methodology and especially around the effect of a curved trawling method. One possibility is that herding to the sides by the vessel will lead to increased catch, which could overestimate the mackerel density in the sea (Nøttestad et al., 2015). There is also the concern that different vessels have different catchability, which may create bias in the data due to the four vessels used in the IESSNS survey in order to cover such a large area over a relatively short period of time. Discussions whether mackerel is distributed evenly enough throughout the ocean during the feeding season in summer to be used as a swept area index on abundance, are also a heated topic. A highly aggregated and patchy distribution may lead to a need for many more trawl stations or result in bias in the final assessment (Nøttestad et al., 2016b).

1.4 OBJECTIVES

The International Ecosystem Summer Survey in the Nordic Seas (IESSNS) has a need for several investigations and possible improvements surrounding different parts of the swept area methodology for abundance estimation of NEA mackerel. Access to new underwater technology, IESSNS catch data and a week-long methodology cruise conducted ahead of the 2015 survey makes it possible to do a lot of investigations with the aim of improving the methodology and reduce the uncertainties. The major aim of this thesis is to study aspects of the pelagic trawling technique (curved trawling versus straight forward trawling) used during the IESSNS survey and it is divided into two parts:

The primary objective is to determine whether the current IESSNS protocol with curved trawling, specifying a constant starboard turn in order to keep the trawl outside of the wake zone (propel water), is necessary. Trawling in a constant turn is believed to reduce vessel avoidance and result in less bias in the catch data. However, it is an awkward way of pelagic trawling and it is challenging to maintain the trawl's symmetry when trawling in strong currents or poor weather.

The secondary objective is to study how mackerel is distributed in the ocean as reflected in how even passage rates through the trawl are throughout the duration of the pelagic trawling. A swept area trawl survey based upon sampling at pre-assigned stations is most suitable when the target fish are evenly distributed in the trawl's path (see Nøttestad et al. 2015). More heterogeneous and patchy distribution leads to a higher need of more trawl samples and generally results in higher bias in the sampled trawl data (Gunderson, 1993).

2 MATERIALS AND METHODS

2.1 GEAR RIGGING AND OPERATION

2.1.1 TRAWL RIGGING

The pelagic trawl used in the surveys was the Multpelt 832 trawl shown in figure 2.1, which was constructed. The trawl was developed as a standardized sampling trawl for the IESSNS survey by the cooperating national institutes form Norway, Faroe Islands and Iceland (ICES, 2013; Nøttestad et al., 2016b). The Multpelt 832 is made of polyamide with an opening circumference of 832 m and mesh sizes from 16 m in the front and wings, to 40mm at the codend. The trawl is operated at 5 knots (speed over ground, measured by GPS) with 80 m sweeps (Dyneema) and 350 m warps (Dyneema) (figure 2.2) (ICES, 2013; ICES, 2014b). A 4.6 m^2 kite at the center of the headline provides lift and buoys attached to the intersection between the sweeps and the wing tips provide lift to the wings. This ensures that the entire headline is kept at the surface so fish do not escape over the trawl.

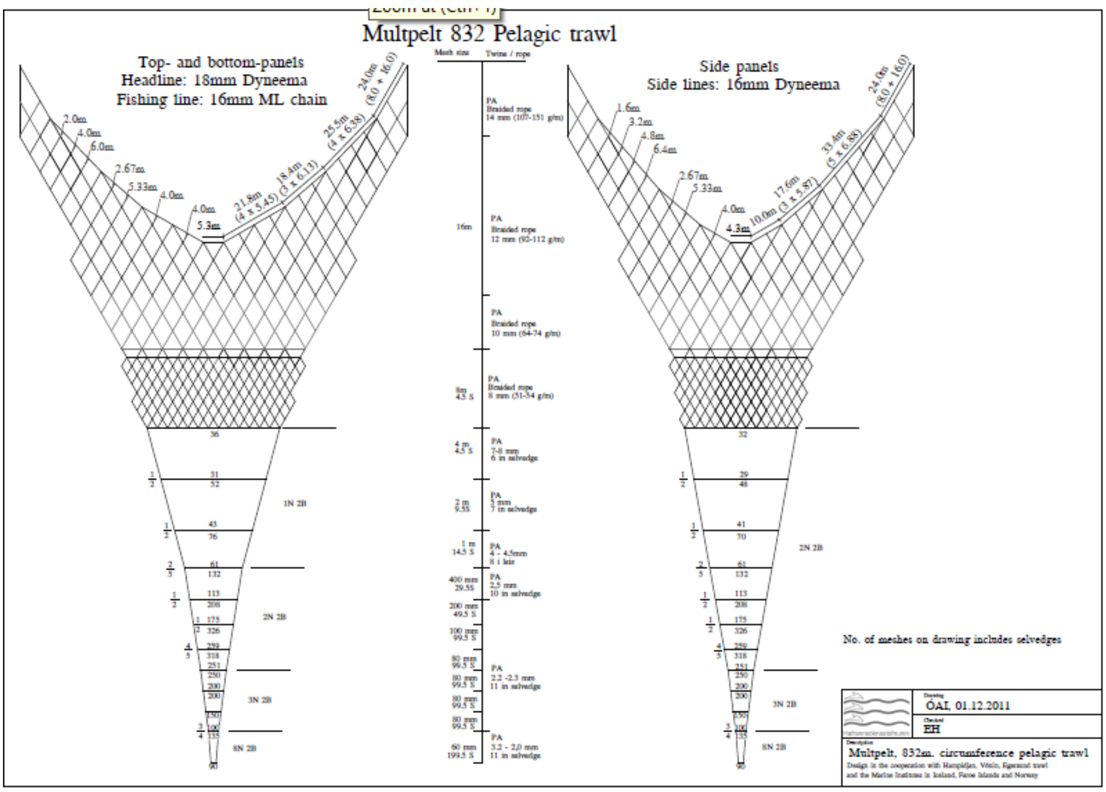

Figure 2.1. Illustration of the Multpelt 832 with fishing line, headline, top, bottom and side panels and side lines.

A chain of 400 kg was attached to the lower wing tips. SeaFlex trawl doors (Egersund trål AS, Egersund, Norway) with an area of 7,5m^2 were adjusted to get a door spread at 110-120 m and a depth of 20 m, resulting in a foot rope depth of 30-35m and wing spread of approximately 65m. A fish lock was attached in front of the codend to prevent fish from swimming back forward inside the trawl during heaving. The fish lock is constructed with a panel of netting where the leading edge is attached to the codend roof and the other end is loose. During trawling, the water flow causes the panel to lay against the codend roof. As the speed is reduced during hauling, the loose end of the panel falls down to the bottom of the codend, preventing fish from swimming forward. This is important because fish allowed to swim forward in the trawl can especially under heaving potentially escape through large meshes or through the opening of the trawl.

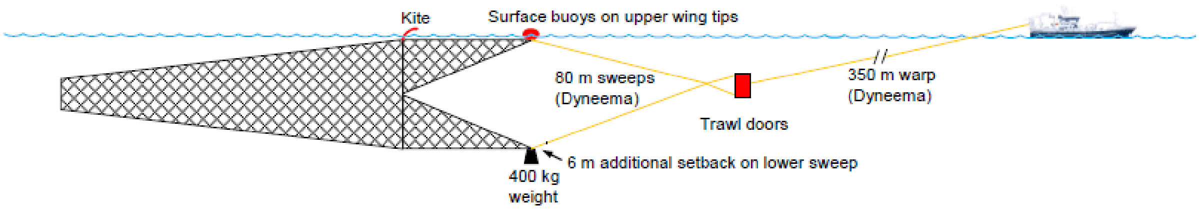

Figure 2.2. Schematic illustration of the multpelt 832 with gear and vessel, seen from the side. The multpelt 832 is rigged with 350 m warp, 80m sweeps, buoys, a kite and 400 chain weights on each lower wing.

2.1.2 TRAWL OPERATION

Two types of trawling techniques with the same trawl rigging were applied: straight forward trawling (classic trawling) and curved trawling. Trawling time varied from 14 – 45 minutes, but was standardized to number or weight of fish per 30 minutes to allow comparisons between the hauls. Towing speed was 5 knots for all investigations.

During straight forward trawling, the trawl ends up in the middle of the vessel wake and is then trawling the same area as the vessel has passed over. When trawling in a curved manner, the trawl is operated in a specific way (Figure 2.3.) After 350 m of warps is released from the vessel, it turns slightly (approximately 5 degrees) to starboard. The turn is kept throughout sampling period, with small adjustments to the vessel's course so the surface float on the port upper wing tip stays approximately 20 m on the starboard side of the propeller wake. This places the port door in the vessel's wake, positioning the trawl entirely to starboard of the wake. The vessel maintains a straight forward course during heaving in order to bring the trawl onboard.

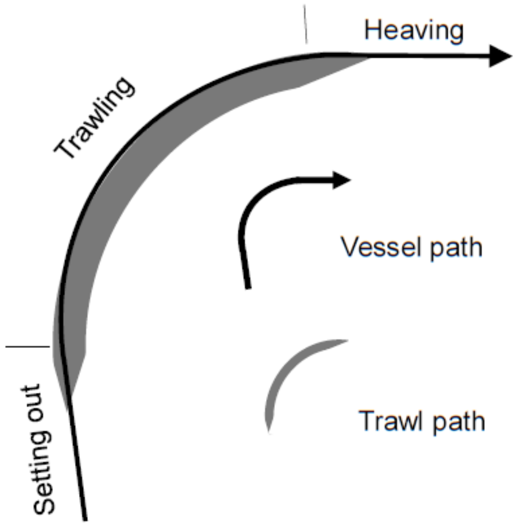

Figure 2.3. Illustration of curved trawling. The trawl is set in a straight line, and when shooting (setting out) is done the vessel goes into a turn. The turn lasts until the trawling period (usually 30 minutes) is done, before it straightens out again during heaving.

2.2 DATA COLLECTION

Data analysis in this thesis was collected from the 2015 IESSNS survey and a week-long methodological cruise right before the IESSNS survey began. Total catch data with species distribution was collected in both surveys, while DV data and GoPro videos were only collected during the Methodological cruise. The study used four different vessels and a test after vessel effect was done. In addition, tests were conducted to if there was any difference between starting the with curved trawling followed by trawling in a straight line and starting with a straight forward trawling before trawling in a curved procedure.

Having two cruises plus variations in how data was collected on each cruise resulted in four different types of comparative data. The first type of data was collected from total catch weight data when several hauls were collected at one location, which made for more than one pair of alternating trawl hauls. The second type of data were collected from total catch with only one alternating trawl pair done at each location. Similarly, DV entrance rate data were collected both with only one alternating trawl pair for each location and with more than one alternating trawl pair collected from each location. The different comparisons, including the number of replicates of each type of comparison, are illustrated in Table 2.1. A test was done to look for any differences in results between the methods.

Table 2.1. Overview of the different methods of collecting comparative data, including the effective number of alternating hauls comparisons for each method.

	1 alternating pair for each location	> 1 alterating pair for each location
DV data, methodological survey	5 comparisons	5 comparisons
Total catch data, methodological and IESSNS survey	16 comparisons	9 comparisons

2.2.1 METHODOLOGICAL CRUISE

Data was collected during a methodological cruise aimed at improving the trawling technique used on the IESSNS survey in order to increase the precision of the survey and reduce possible sources of bias. Trawling was conducted from 22th to 28th June, 2015 along the Norwegian coastline between 60°N and 61°N on board the Norwegian vessels R/V “G.O. Sars” (77.5 m, 8100kw power) and M/V “Brennholm” (75.4m, 9300 kW power) (Figure 2.4).

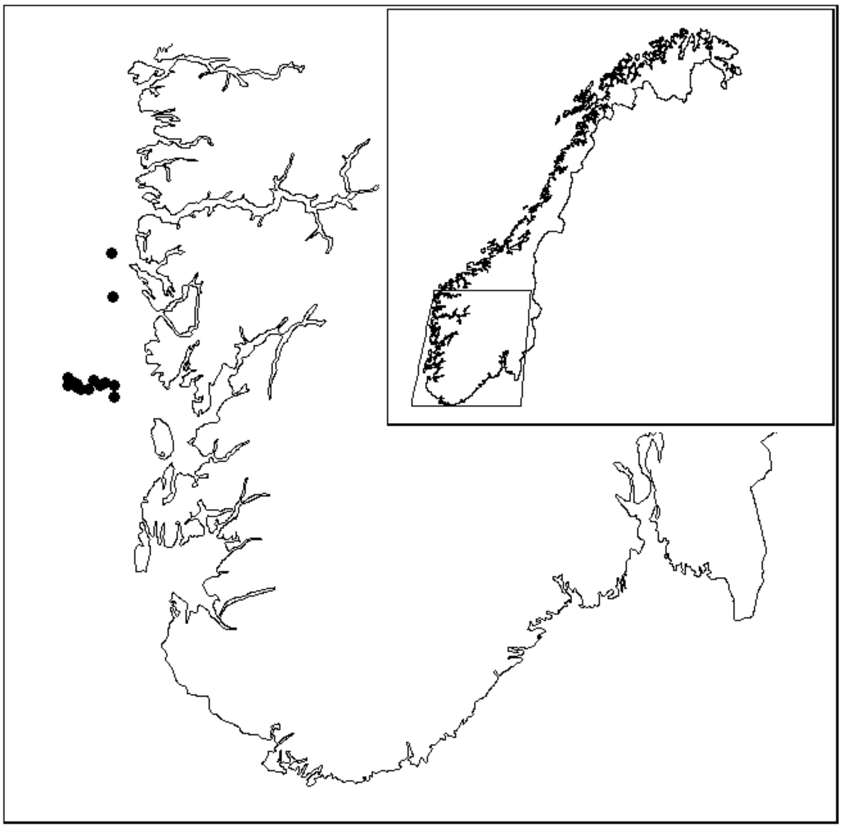

Figure 2.4. Trawl haul stations during the methodological cruse. The data was collected with R/V ”G.O.Sars” and M/V ”Brennholm” and includes as a combination of hauls where Deep Vision data were collected and hauls without Deep Vision where comparisons were made using total catch weight.

Eleven pelagic trawl hauls were conducted by R/V “G.O.Sars” with the DV unit, six of which were suitable for further quantitative analyses (Table 2.2). This made for ten pairs of alternating hauls (curved and straight forward trawling).

Table 2.2. Overview of stations with Deep Vision data collection, methodological cruise R/V “G.O.Sars”.

Station	Trawl method	Date	Entrance counts	Start time (UTC)	Duration (minutes)
192	Straight	24.06.2015	91	05:30	30
192	Curved	24.06.2015	275	06:05	30
193	Straight	24.06.2015	357	11:50	30
193	Curved	24.06.2015	35	11:20	30
194	Straight	24.06.2015	423	17:30	45
194	Curved	24.06.2015	912	18:00	45
195-196	Straight	25.06.2015	1716	08:00	30
195-196	Curved	25.06.2015	1845	08:30	30
197	Straight	25.06.2015	176	12:05	30
197	Curved	25.06.2015	894	12:35	30
199a	Straight	26.06.2015	1101	05:43	30
199a	Curved	26.06.2015	354	06:13	30
199b	Straight	26.06.2015	123	06:43	30
199b	Curved	26.06.2015	336	07:13	30
199c	Straight	26.06.2015	65	07:43	30
199c	Curved	26.06.2015	530	08:13	30

There were several reasons for excluding the remaining hauls including technical difficulties with the DV unit and the trawl along with inconsistency in the trawl operations as multiple experiments were being carried out during the cruise. Hauls were divided into periods where trawling occurred in a straight forward line and periods where trawling occurred in a curve track. Four of the hauls had one period with straight forward pelagic trawling and one period with curved trawling (one pair of alternating hauls). The last haul (199) had three periods on each type of trawling method, which made for five comparable alternating pairs instead of one each as the other hauls gave (Table 2.1). This is because each trawling method could be compared to the trawling method conducted both before and after. No biological samples from the DV unit hauls was used in this in this study, as fish lengths could be measured directly from the DV images. Also, the trials with the DV included a split placed just in front of the codend to reduce the total catch which could introduce error if the size of the fish escaping through the split was not completely random. The split allowed excess fish to escape and was used because of a limited need for biological samples and to prevent large catches since the DV hauls were sometimes several hours in duration. Haul 195 and 196 was two different test combined into one haul. The first period (195) was conducted during straight forward trawling with the head rope at 30 m depth (the kite was deactivated and floats at the wing tips were removed) in order to look for fish under 30 meters, while the second period (196), which was used in this study, was done in the surface as the other hauls. The codend was not emptied between the deep and shallow periods, resulting in combined catch from this set of hauls. Review of Deep Vision data showed that no fish were captured during the deep trawling period.

After the eleven trawl hauls were done with the DV unit, it was removed from the trawl, the split was sewn shut and nine total catch hauls were conducted with R/V "G.O.Sars" and M/V "Brennholm" (Table 2.3). The hauls were collected in the same area as the DV hauls (Figure 2.1) following the same trawling procedure. Total catch weight was compared between the different methods of trawling and 100 fish were randomly subsampled from the catch and used to determine species composition and length distribution following standard Institute of Marine Research protocol (Mjanger et al., 2011). Length data from station 204 was not found in the database following the cruise, so the length comparison between 204 and 205 was removed. In addition, the total catch at station 3 (Brennholm) was only 60 fish, all of which were measured for length distribution analysis. The nine hauls made for five pairs of comparable total weight measurements

Table 2.3. Overview of stations, total catch weight data collection, methodological cruise R/V "G.O.Sars" and M/V "Brennholm".

Station	Date	Mackerel (Kg)	Start time (UTC)	Method	Vessel	Duration (minutes)
202	27.03.2016	307	14:02	Curved	G.O.Sars	20
203	27.03.2016	254	15:40	Straight	G.O.Sars	20
204	28.03.2016	450	06:34	Curved	G.O.Sars	30
205	28.03.2016	730	08:20	Straight	G.O.Sars	35
206	28.03.2016	961	10:00	Curved	G.O.Sars	30
1	27.03.2016	1107	11:25	Straight	Brennholm	14
2	27.03.2016	688	12:54	Curved	Brennholm	15
3	27.03.2016	18	14:15	Curved	Brennholm	15
4	27.03.2016	291	15:43	Straight	Brennholm	15

2.2.1.2 VIDEO AND PICTURE COLLECTION

During the methodological cruise, stereo pictures were collected with the DV unit and video was collected using GoPro cameras.

2.2.1.2.1 DEEP VISION UNIT

The Deep Vision (DV) is a frame containing a calibrated stereo camera, a pair of strobe lights, battery and a PC for controlling the cameras and saving the images which are downloaded to a computer onboard the vessel at the end of each haul (Rosen et al., 2013). It was only used in the methodological cruise. The Deep Vision frame is mounted 3 m in front of the codend, and has nets which force all fish to pass through the camera's field of view before entering the codend (see Figure 2.5). Every passing fish is photographed at least once, due to the five pictures per second taken by the DV unit stereo camera. The pictures are full colour and well lit, which makes it easy to determine passing species by visual inspection. The stereo pictures can be used to measure fish length, using the Deep Vision software (developed by Scantrol Deep Vision AS).

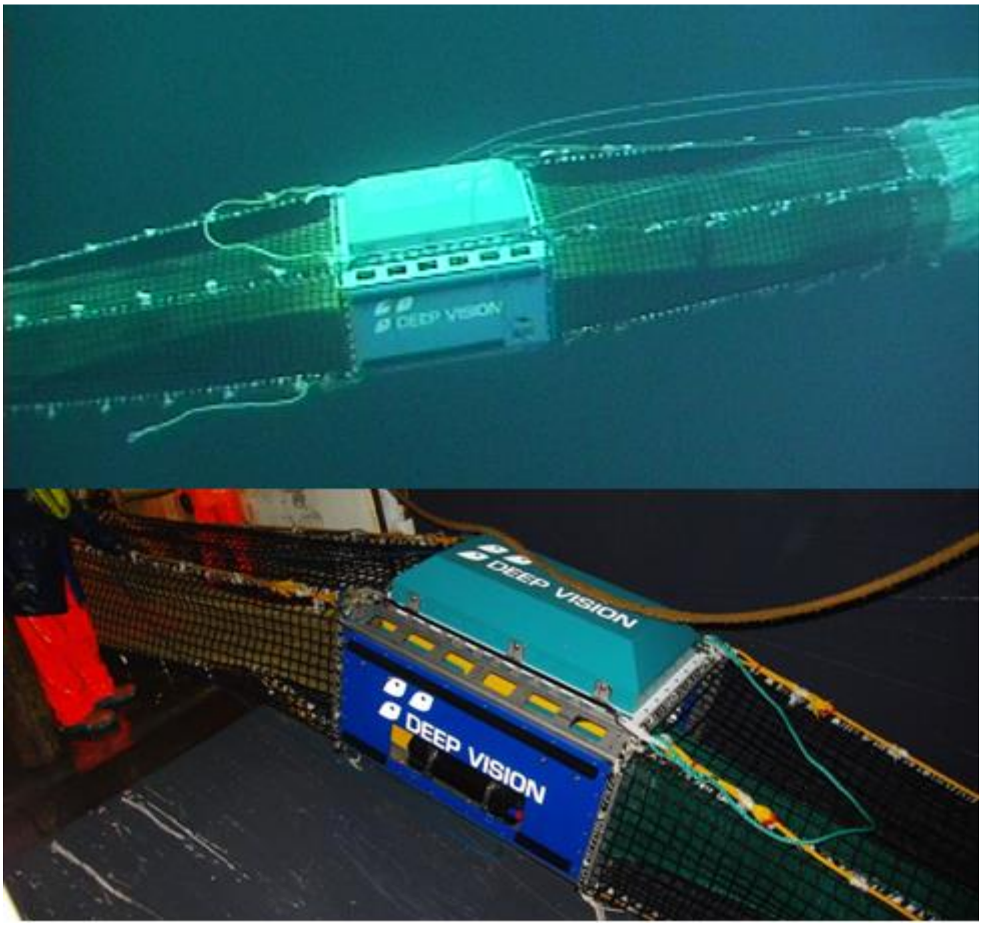

Figure 2.5. Deep Vision (DV) unit underwater mounted in the multpelt 832 trawl (top) and on the way on board after a trawl haul (bottom).

2.2.1.2.1 GOPRO CAMERAS

GoPro HERO3 and HERO4 action cameras were used in the methodological cruise and collected video data inside the trawl 65 m forward of the Deep Vision unit (between 200 mm and 400 mm meshes). The cameras have a wide field of view and are suited for underwater observation where there is enough natural light. The footage shows clear silhouettes of fish which makes it a good tool for counting rates, but it is hard to determine species. The cameras were placed inside a metal cage for protection, which was attached to the trawl meshes of the under panel by using a thin rope (figure 2.6, left). Differences between mackerel and herring are most apparent from a dorsal view, but a camera mounted in the over panel, looking down, would have insufficient illumination to pick out fish from the darkness of the water column.

Figure 2.6. GoPro cameras attached to the under panel of the trawl (left), GoPro video taken from the camera pointing up (middle) and GoPro video taken from the camera pointing backwards (right). GoPro video was collected in colors, but converted to black and white in order to improve contrast for analysis.

Two GoPro cameras were used, one pointing upward and the other pointing backward (Figure 2.6, middle and right). The upwards pointing camera was used to get video of fish silhouettes, but it did not cover the whole cross section of the trawl. Backwards orientation provided video with a larger field of view, and the camera faced backwards to prevent fish, jellyfish, or other objects from covering the lens. During analysis of the video data it became clear that the images from the backwards facing camera had insufficient contrast to be sure that every fish was counted and that no fish were double-counted. Analysis using a combination of the two cameras proved to be too challenging and too time consuming for the small amount of additional information gained, so the backward facing camera analyses were cut out. A third GoPro camera was placed 3 meters ahead of the Deep Vision in order to see if fish accumulated in front of the Deep Vision, but data from this camera were not analyzed quantitatively. Locations of the GoPro cameras and Deep Vision are illustrated in Figure 2.7.

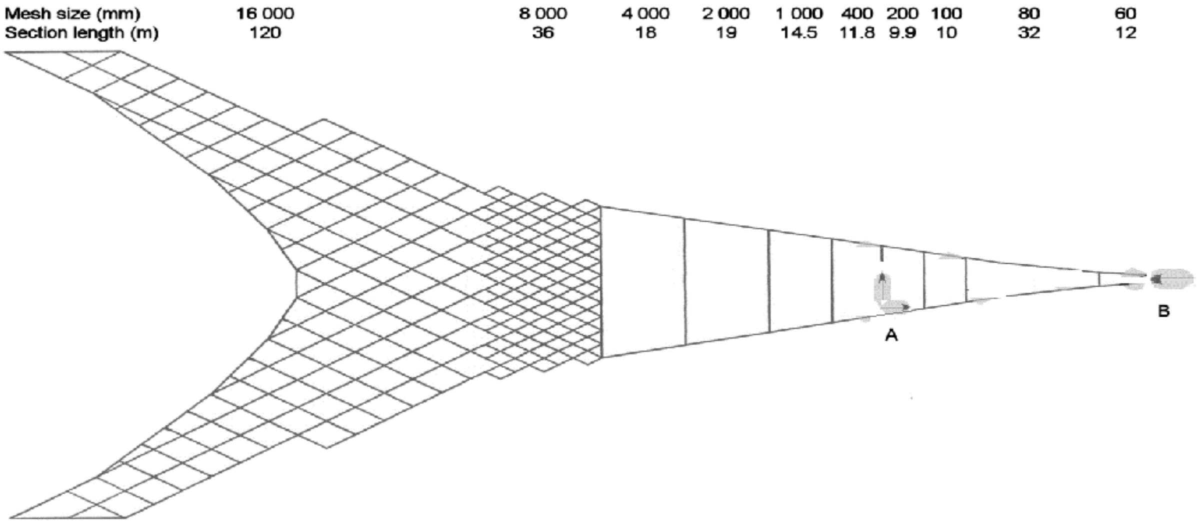

Figure 2.7 Schematic illustration of the Multpelt 832 seen from the side. Two GoPro cameras were attached at the intersection of 200 mm and 400 mm meshes (arrow A) and the DV unit plus a third GoPro camera were attached at the very end of the trawl where the codend attaches (arrow B). One camera at location A pointed straight upwards while one pointed backwards. The single camera at location B pointed forward in the trawl.

2.2.1.3 ANALYSIS

The DV data were used to investigate if there were any differences in the catch rate and length distribution during curved and straight forward trawling. In addition, the DV data was used in a distribution analysis to look how the mackerel was distributed in the sea over the time- and distance scale of a single haul and, in combination with the GoPro data, to do a fish size over time analysis. This was done to test whether differences in swimming capacity lead to size related differences in aggregation in front of the DV unit. A flow rate analysis was also done to investigate if water flow in the aft portion of the trawl was different between straight and curved trawling. This was because the curved trawling has a slightly shorter trawl path compared to the straight forward and therefore moves slightly more slowly through the water even if the vessel has the same towing speed. The total catch data and length distribution taken during the last five comparisons (Table 2.3), was analyzed together with a larger set of similar data collected during the 2015 IESSNS survey.

2.2.1.3.1 CATCH ANALYSIS

A simple image viewing software (Windows photo viewer, Microsoft Corporation) was used to count entrance rates, record behavior and identify species in the images collected by the Deep Vision because these analyses did not require stereo photos and it is more difficult to quickly scan through images using the Deep Vision software (each 30 minutes of trawling generated 9 000 image pairs). The analysis was based on visual assessment, and the fish were counted when they left the screen on the codend side of the DV unit (Figure 2.8). In order to avoid double-counting fish that swam forward through the DV, the next fish passing out on the codend side was not counted, and thus took the place of the forward-swimming fish instead of being counted. To be sure that straight forward and curved trawling were separated in the comparing study, only the 14 final minutes of the trawling period were analyzed. This left a 15 – 30 minutes period to clean out fish from the previous trawling method and transition period.

Figure 2.8. Example picture taken by the DV unit showing 20 mackerel. Fish arrive from the right (vessel side) and depart on the left side before entering the codend.

2.2.1.3.1 DV LENGTH ANALYSIS

Deep Vison Software was used to measure mackerel length in all of the DV hauls in both curved and straight forward trawling. The Deep Vison Software uses the paired stereo images from the DV stereo camera to create a three dimensional coordinate system. A point is placed in right picture using a mouse click, and the software finds the matching point in the left picture using a pattern recognition algorithm. The point is then given coordinates, and when a new point is made the software will estimate the length between the points. When possible, three points were used on each fish in order to best follow the lateral line. More than three points were used for heavily bent fish. Since the software must find matching points on the fish, it is not possible to measure total length for species with forked tails such as mackerel and all Deep Vision length measurements are therefore fork length. An example length measurement is shown in Figure 2.9

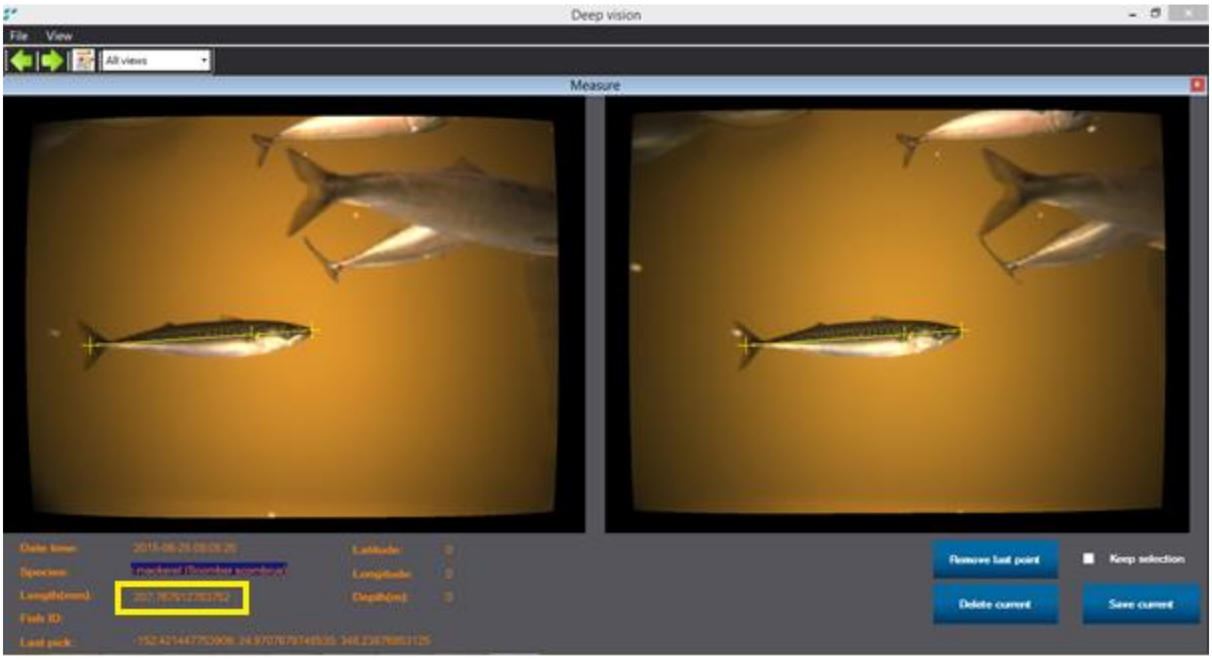

Figure 2.9. Deep Vision software being used to measure a mackerel along the yellow line leading from snout to pectoral fin to tail. Calculated length (208 mm) is indicated in the yellow box in lower left corner.

In some cases, only parts of a fish were visible in an image, or the fish was oriented on the camera axis, which makes it impossible to pinpoint both snout and tail. In many of these cases, partial measurements could be made from sequential pictures and added to calculate length of the entire fish. When this was not the case (approximately 5 % of the fish) the fish could not be measured. The length distributions were compared using a Kolmogorov-Simonov test to investigate if there were any differences in length distribution between curved and straight forward trawling. Cumulative distribution plots were generated for every comparison and were used to determine which way length composition differed in the hauls where Kolmogorov-Simonov test results were statistically significant.

2.2.1.3.3 DISTRIBUTION ANALYSIS

The entrance rates were also used for an investigation of how the mackerel was distributed in the sea, by looking at how fish entered the DV unit over the last 14 minutes of each trawling period. A plot was made to show the number of fish entering per minute for every second minute during the last 14 minutes of each method of trawling (total number of fish entering in 7 minutes). This made it possible to see if the distribution was uniform or aggregated by looking at how the entrance percentage changes over the seven data points. The closer each minute total is to 14.3 % (1/7), the more evenly distributed is the fish. However, this analysis was designed to investigate large differences over a relatively short time period and is not a quantitative analysis, so it has limitations in terms of detecting small differences and trends.

2.2.1.3.4 DELAY ANALYSIS

The comparative analysis using DV unit will not work if fish aggregated in front of the DV unit, so two of the hauls (PT 197 and PT 199) were chosen for a study to compare how long distinct aggregations took to pass between GoPro camera position A (between 200 and 400mm meshes) and the DV unit 64 meters farther back in the trawl. A 10-15 minute interval with minimal amount of herring was chosen, since it was difficult to distinguish between mackerel and herring in the GoPro videos, and the entrance rates in each location were compared. The two intervals which fulfilled these criteria were both straight forward towing periods. Cameras attached on the vessel side of the DV unit were also used to look for aggregation of fish right in front of the DV unit. VLC Media Player (VideoLan organization, http://www.videolan.org/vlc/) was used for playing videos from the GoPro cameras. The settings were adjusted to black and white, and the contrast was turned up to better visualize the silhouette from fish passing overhead of the camera. The video was used to look for behaviour and accumulation of fish both at the seam between 200 and 400mm meshes and directly ahead of the DV unit.

2.2.1.3.5 FISH SIZE OVER TIME ANALYSIS

A size over time analysis was done to look for any size related order of passage within a group. The analyses was performed by following a group of mackerel from a point where there was a ten seconds gap without fish in the DV unit, and ended after a 10 second gap without fish. All of the analyzed periods were taken during straight forward trawling from hauls 193, 197 and 199a. This was because the analysis was done together with the delay analysis, so the hauls ended in the same periods. Analysis of 193 was ultimately rejected from the delay analysis due to the presence of a large amount of herring, which made accurate GoPro counts impossible.

2.2.1.3.6 WATER FLOW ANALYSIS

The water flow was measured inside the DV unit using the same technique as fish length measurements, except that passive object were targeted instead of fish. Jellyfish and krill were pinpointed in two consecutive pictures (time difference of 0.200 seconds) and the coordinates were noted down and the distance moved was calculated. Five passive objects from each of the DV unit hauls (192,193,194,195-196, 197 and 199 a, b and c) and from both the alternating trawling techniques were measured for speed. This made for 80 flowrate measurements where equation 2.1 (below) was used to calculate flowrate.

$$Flow\ rate = \frac{Distance}{Time}$$

Equation 2.1. Calculation of flow rate through the DV unit

2.2.2 IESSNS SURVEY

In addition to the methodological cruise, data collected during the 2015 IESSNS survey are included in this thesis. The IESSNS survey data consists of catch weight and length distributions from twenty-four alternating hauls where straight and curved trawling were carried out with only a short gap in time and space between. The data were sampled with three different survey vessels, R/V “Árni Friðriksson” (70m,4300 kW power), M/V “Brennholm” and M/V “Eros” (77,5m, 7400 kW power). However, length distribution data from Árni Friðriksson was excluded from the study as it was not accessible through the IESSNS database. This left eleven alternating hauls containing length distribution. Two of the comparisons had a zero catch in the curved trawling method, and were removed from the analysis as outliers and because they would result in undefined or infinite ratios. Ultimately, twenty alternating haul pairs could be used for comparisons (Table 2.4). In nine of the locations, only one alternating pair was conducted while the two Greenlandic locations had two and seven sets of alternating hauls (Table 2.1).

Table 2.4. Overview of stations, total catch weight data collection, IESSNS survey R/V “Árni Friðriksson”, M/V “Brennholm” and M/V “Eros”

Location	Mackerel (Kg)	Method	Vessel	Duration (minutes)
1	124	Straight	Árni Friðriksson	15
1	173	Curved	Árni Friðriksson	15
1	55	Straight	Árni Friðriksson	15
2	108	Curved	Árni Friðriksson	30
2	2635	Straight	Árni Friðriksson	30
2	127	Curved	Árni Friðriksson	30
2	204	Straight	Árni Friðriksson	30
2	71	Curved	Árni Friðriksson	30
2	104	Straight	Árni Friðriksson	30
2	32	Curved	Árni Friðriksson	30
2	112	Straight	Árni Friðriksson	30
3	502	Curved	Eros	30
3	314	Straight	Eros	30
4	2310	Curved	Eros	30
4	4206	Straight	Eros	30
5	2572	Curved	Eros	30
5	5114	Straight	Eros	30
6	3450	Curved	Eros	30
6	2321	Straight	Eros	30
7	1678	Curved	Eros	30
7	8291	Straight	Eros	30
8	1152	Curved	Eros	30
8	498	Straight	Eros	30
9	5189	Curved	Brennholm	30
9	2718	Straight	Brennhom	30
10	1384	Curved	Brennhom	31
10	182	Straight	Brennhom	30
11	161	Curved	Brennhom	30
11	1249	Straight	Brennhom	30
12	2412	Curved	Brennhom	29
12	362	Straight	Brennhom	30
13	386	Curved	Brennhom	30
13	2860	Straight	Brennhom	30

2.2.3.1 STUDY AREA

Twenty-two of the hauls (eleven sets of comparisons) were carried out in Norwegian zone and the rest in Greenlandic zone (See figure 2.10).

Figure 2.10. Locations of comparative trawl haul stations during the IESSNS survey. R/V ”Árni Friðriksson” collected the data near Greenland, and M/W ”Eros” and M/V ”Brennholm” collected the data near Norway. Map from Nøttestad et al. (2015).

2.2.3.1 ANALYSIS

Total catch weight and length distributions measured during the cruise were used for a comparison analysis between curved and straight forward trawling following the same procedures described for the methodology cruise in section 2.2.1 above.

2.3 STATISTICAL ANALYSIS

A number of different statistical tests were used in the analyses, which included investigations to look for sampling effects due to vessel, start method (whether straight or curved trawling was done first) and whether haul comparisons were one-to-one or one-to-many (data from during several hauls at one location, all the Árni Friðriksson data). The effect of the different sampling techniques was tested by finding the percentage of hauls which had a higher catch of mackerel in the curved trawling and using a single sample t-test to determine if the result was statistically significant. A generalized linear mix model (GLMM) was run to see whether counts from the alternating straight and curved trawl technique differ with the assumption of a skewed distribution pattern (quasi-Poisson distribution was selected because the data is over-dispersed counts). The nonparametric Kolmogorov-Smirnov test was used to look for differences in length distribution between paired straight and curved hauls. In addition, the distribution percentages were statistically tested by a single sample t-test to look if the average entrance rate differed from the mean percentage (14.3%). The flowrate data was statistically tested by running an Anova on a linear model. Wilcoxon signed-rank t-test was chosen to see whether the total catch data differed between straight and curved trawling. A binomial test was done to look after statistical difference between the number of hauls which got higher catch (or counts) during the curved trawling compared to straight forward trawling. The same test was used to look for differences between number of hauls with a significant smaller length distribution in mackerel during curved trawling compared to straight forward trawling. A power analysis was done to look at how many comparisons would have been necessary to find a significant difference between the catches (or counts) in straight and curved trawling given the distributions in the datasets collected. The software package R version 3.1.2 was used in all statistical analysis and most of the plotting. All the statistical tests assumed significance level at $p < 0.05$.

3 RESULTS

3.1 SAMPLING EFFECTS

3.1.1 VESSEL EFFECT

Differences in the relative catches between curved and straight trawling for each of the four vessels are shown in Figure 3.1. Árni Friðriksson had three of nine comparable hauls with higher catches using the curved trawling, Brennholm had three out of seven, Eros had three out of six, and G.O.Sars had five out of thirteen comparable hauls with higher catches using the curved trawling. Based on a one sided t-test, no significant vessel effect was found ($p = 0.09$).

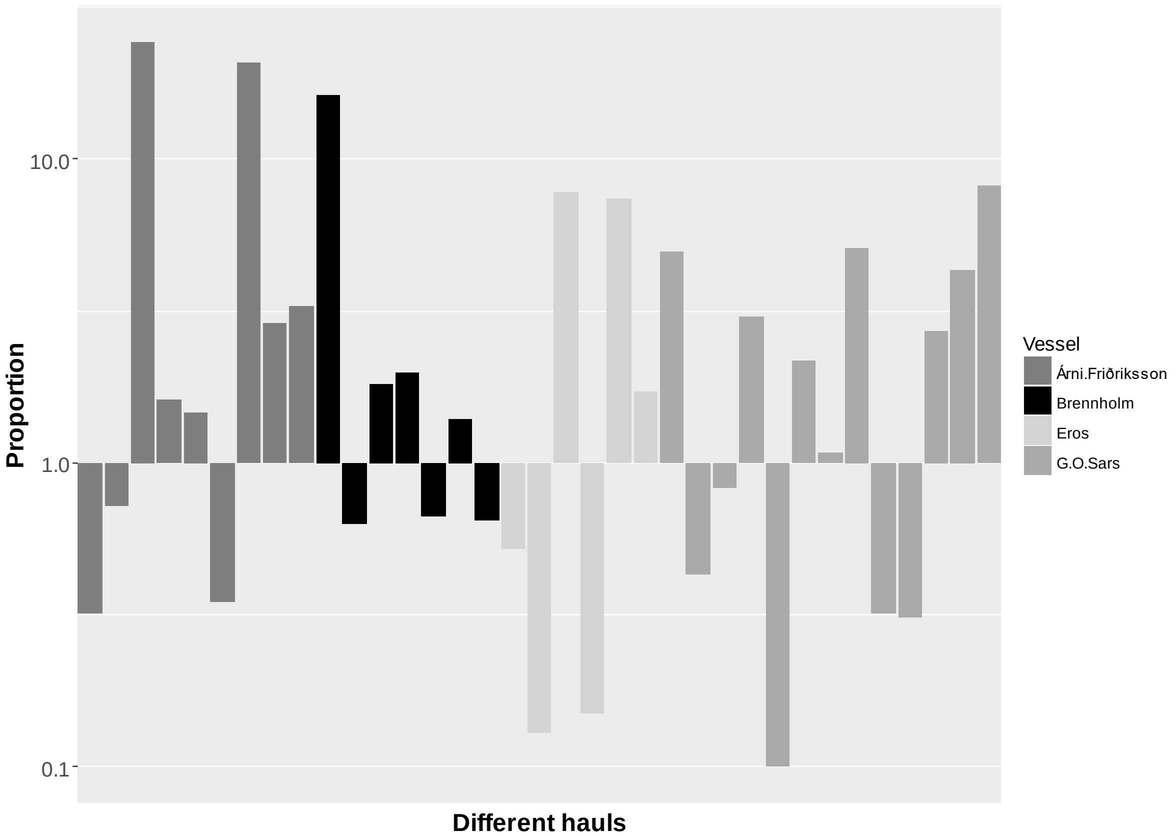

Figure 3.1. Catch proportions (straight forward / curved trawling) for the different vessels. Values > 1 indicate higher catches with straight forward trawling, values < 1 indicate higher catches with curved trawling.

3.1.2 IMPACT OF START TRAWLING METHOD

During this study, 22 out of 35 comparisons started with the curved trawling, and the rest (13 out of 35) started with straight forward trawling (Figure 3.2). Sixty-nine percent of the comparable alternating hauls starting with straight forward trawling ended up with higher catches in the straight forward trawling method and fifty-five % of the stations starting with the curved trawling pattern ended up with a higher catch in the straight forward hauls. No significant catch difference was found between starting the comparable alternating hauls with straight forward trawling versus curved trawling ($p = 0.34$, one sided t-test).

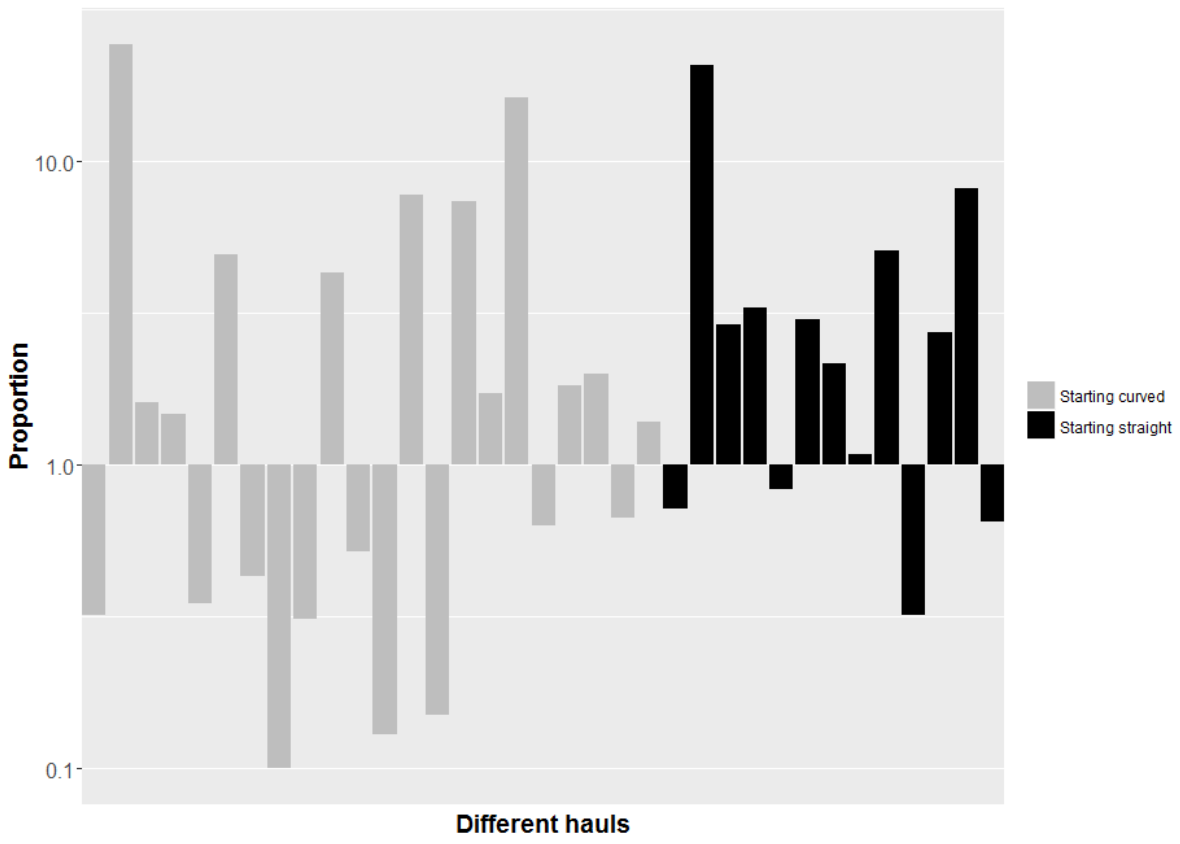

Figure 3.2. Overview over the proportions of catch in straight forward / curved trawling according to the order in which comparison hauls were carried out. Values > 1 indicate higher catches with straight forward trawling, values < 1 indicate higher catches with curved trawling.

3.1.3 COMPARISONS OF ALTERNATING TRAWLING DATA

Four different types of alternating trawling data were collected during this study (Table 2.4). The straight forward trawling had a higher number of hauls with higher catch compared to the curved trawling in all of the haul comparisons (Weight >1 pairs = 66%, Weight 1 pair = 50%, DV >1 pairs = 80% and DV 1 pair = 60%) (Figure 3.3). This indicates a slightly better performance during straight forward trawling but no significant statistically difference in performance was found between the four different alternating trawl data methods (p = 0.11, one sided t-test).

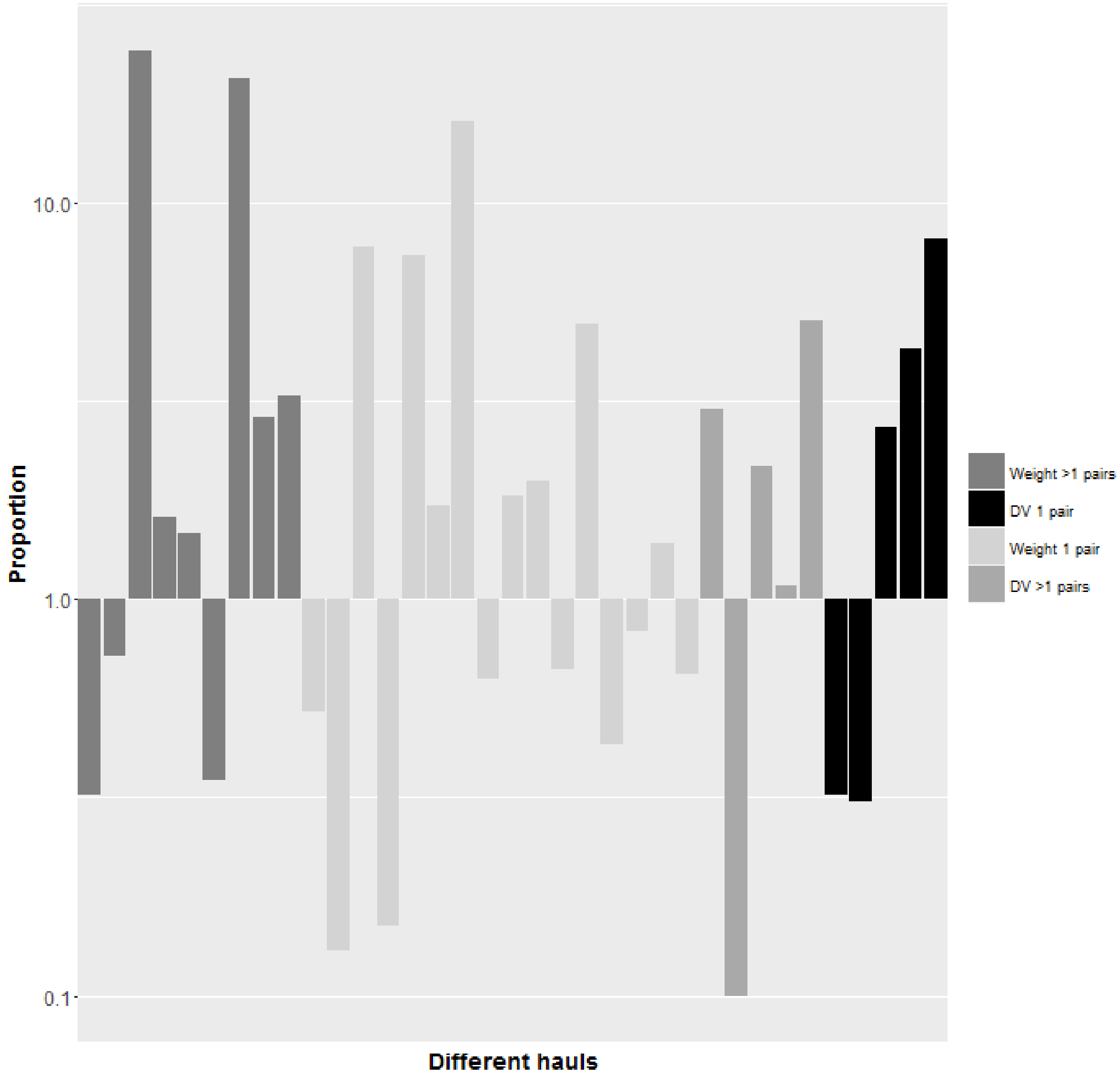

Figure 3.3. Overview of the proportions of catch in straight forward / curved trawling by method (single or alternating hauls, total weight or DV hauls). Values > 1 indicate higher catches with straight forward trawling, values < 1 indicate higher catches with curved trawling.

3.2 DEEP VISION AND GOPRO ANALYSIS (METHODOLOGICAL CRUISE)

3.2.1 COMPARISON BETWEEN STRAIGHT FORWARD- AND CURVED TRAWLING USING DV COUNTS

The comparison between straight forward and curved trawling using the DV unit to count fish showed no statistically significant difference between the two methods ($p = 0.65$). This was based on a GLMM with an assumption of over dispersion and a skewed distribution in the data. Therefore the GLMM was run with a Quasi-Poisson distribution. The straight forward trawling had a higher median value of mackerel catch rates, but the curved trawling had a higher spread as shown in Figure 3.4. Even though we did not find any statistically significant differences between the two trawling methods, the straight forward trawling had almost 15% higher mean value (605 mackerel per haul) then the curved trawling (528 mackerel per haul), indicating a trend towards higher catches in the straight forward trawling. Due to some uncertainty of most appropriate distribution pattern to apply to the data, additional nonparametric statistical tests were run and still no significant difference was found (Appendix A).

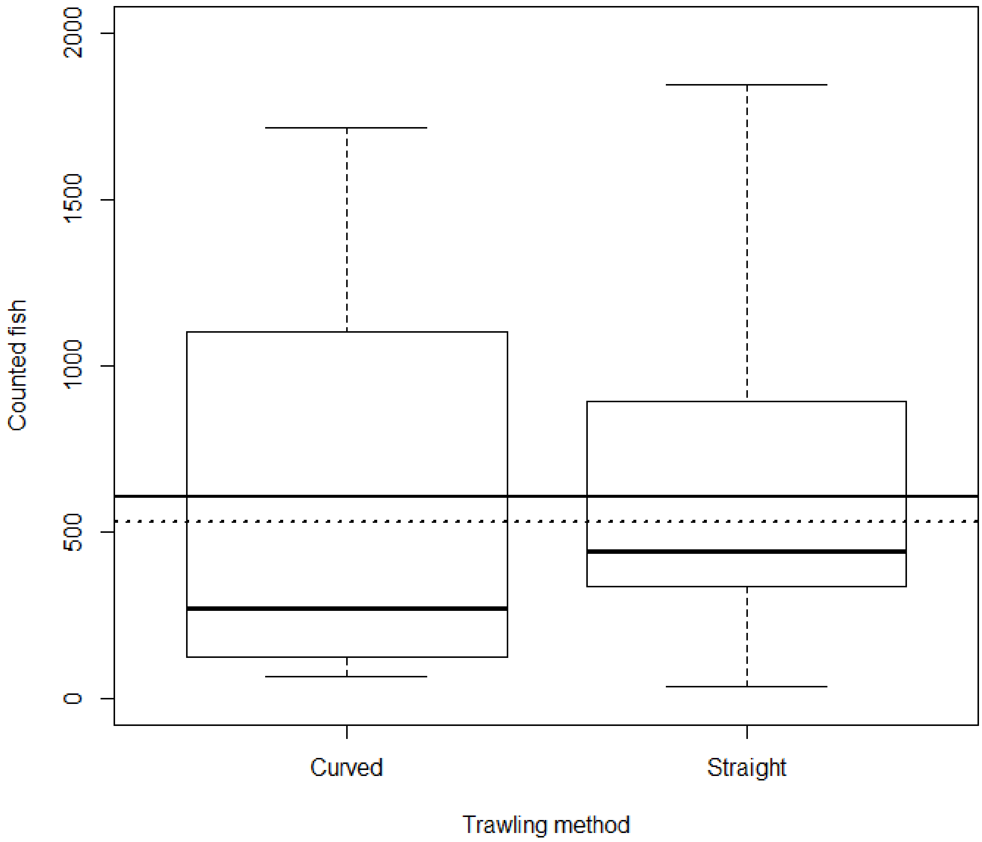

Figure 3.4. Straight forward towing has a lower spread and slightly higher mean and median of fish entrance rate compared to curved towing, but the difference was not statistically significant. The dotted line crossing both boxes represents mean count rate in curved trawling and the solid line crossing both represents the mean count rate during straight trawling. The solid lines within each box represent median value.

3.2.2 LENGTH DISTRIBUTION (DEEP VISION DATA)

An analysis of the length distribution in curved and straight forward trawling combined across all ten stations showed no significant difference based on a Kolmogorov-Smirnov test (p = 0.055). However, this p value is very close to the chosen cutoff of at 0.05 and could indicate a trend towards smaller fish caught during straight forward trawling (Figure 3.5). A significant length difference was found in four out of ten stations (197 $p = 0.0008$, 199a $p = 0.00007$, 199ab p = 0.016 and 199c p = 0.0006, Kolmogorov-Smirnov test). Furthermore, three of the stations (197, 199ab and 199c) had significantly smaller fish in the straight forward trawling compared to in the curved trawling, whereas the last haul (199a) had significantly smaller fish in the curved trawling compared to the straight forward trawling (Appendix B).

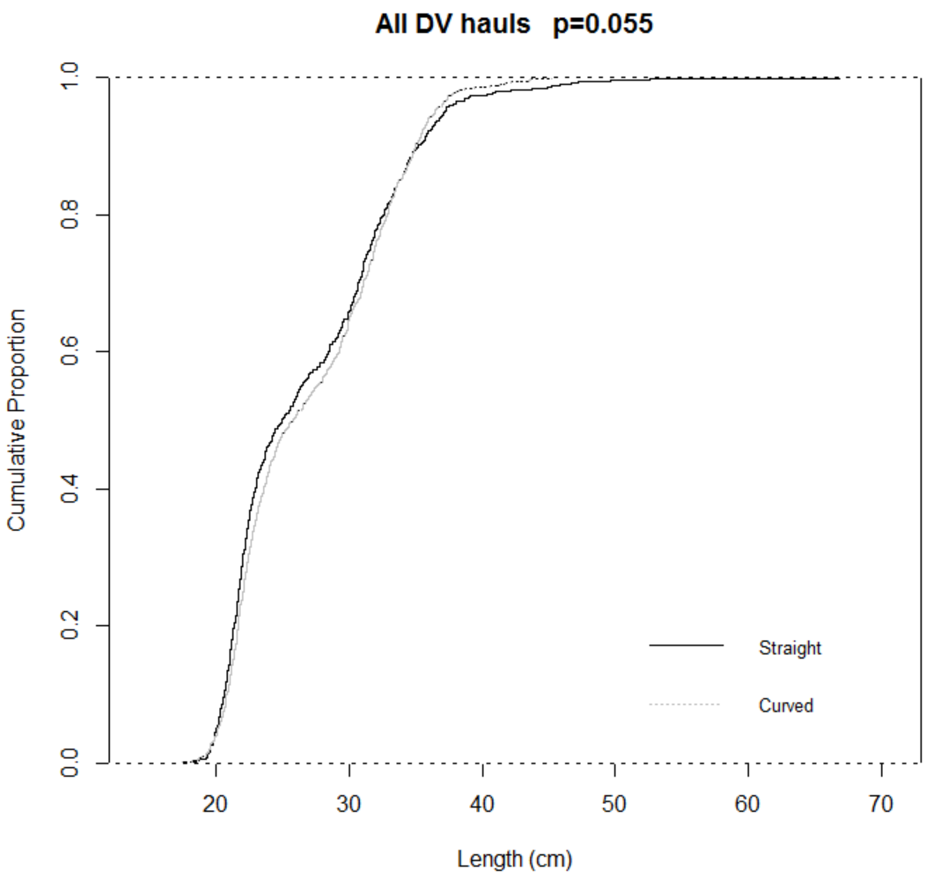

Figure 3.5. Cumulative distribution of all the DV length data during straight forward and curved trawling. The p values represent the difference between the length distributions in the alternating pairs (Kolmogorov-Smirnov test).

3.2.3 MACKEREL DISTRIBUTION ANALYSIS

Analyses of how mackerel were distributed over time within hauls were put forward in order to show how mackerel may be distributed in the sea. The proportion entering during each 1 minute interval did not significantly differ from the predicted 14.3% ($p = 0.99$, one sided t-test). More interesting was that the data shows a wave like entrance rate of the mackerel (Figures 3.5 and 3.6). If the entrance rate had been evenly distributed around 14.3% in all of the seven measuring points, as in the haul “Curved 197”, it would be fair to say the distribution was next to uniform. However, this was generally not the case and indicates that mackerel enter the DV unit in small shoals and loose aggregations. This is especially visible in hauls “Curved 193”, “Straight 199a”, “Curved 199a”, “Straight 199b” and “Curved 199b”. This tendency was also observed in GoPro videos taken 65 meters in front of the DV unit, so it appears unrelated to the presence of the DV. There is no noticeable distribution difference between straight forward hauls (Figure 3.6) and curved hauls Figure 3.7). However, the alternating pairs seem to have a more similar distribution to one another than to hauls outside their set of comparisons. This was especially visible in hauls 192, 196, 197 and 199c.

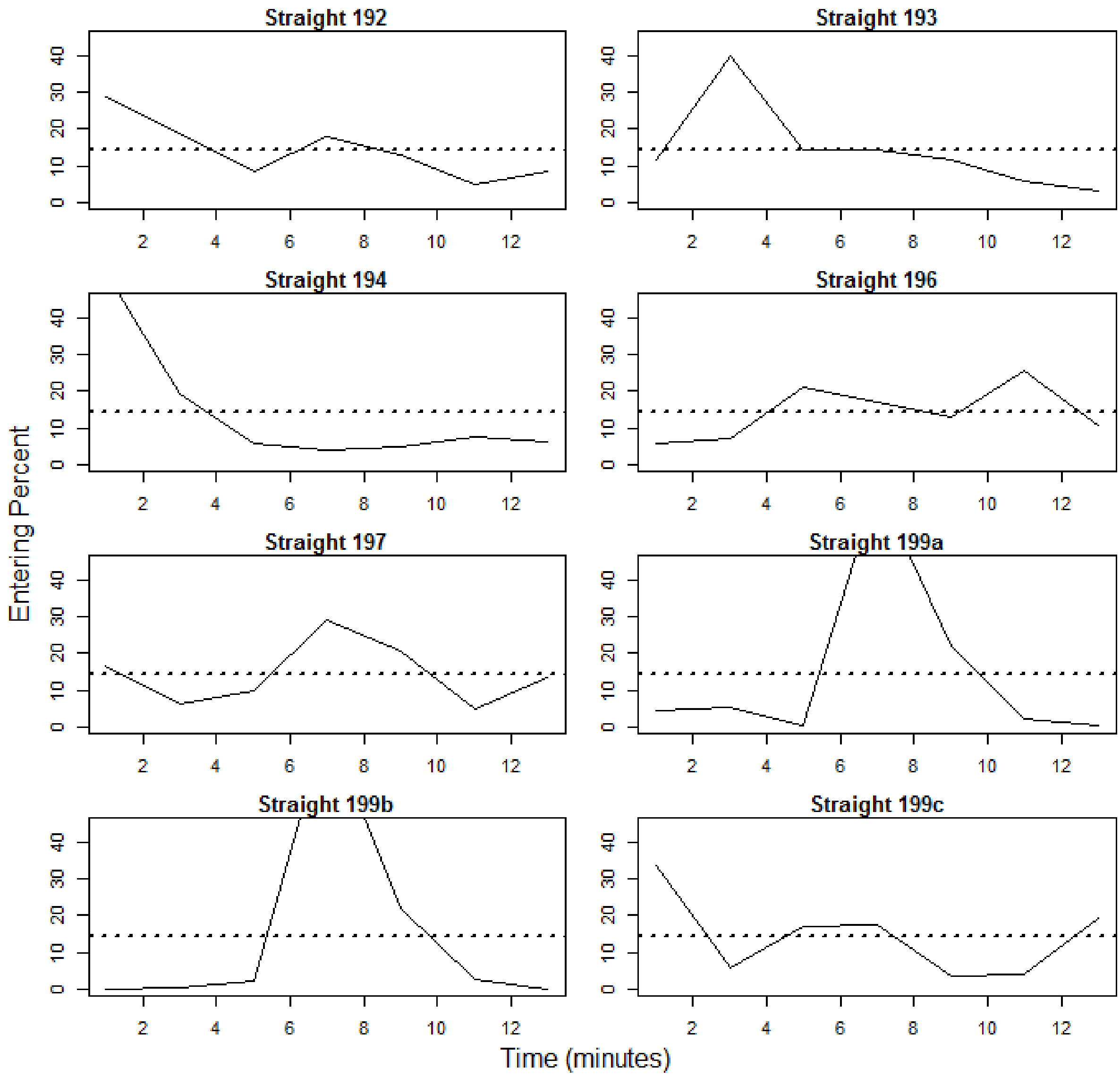

Figure 3.6. Proportion of mackerel from straight trawling passing through the DV unit over time, straight trawling method. The proportion is recorded every second minute during the last 14 minutes of each method of trawling. Dotted line at 14.3 % indicates how a steady flow of fish would appear.

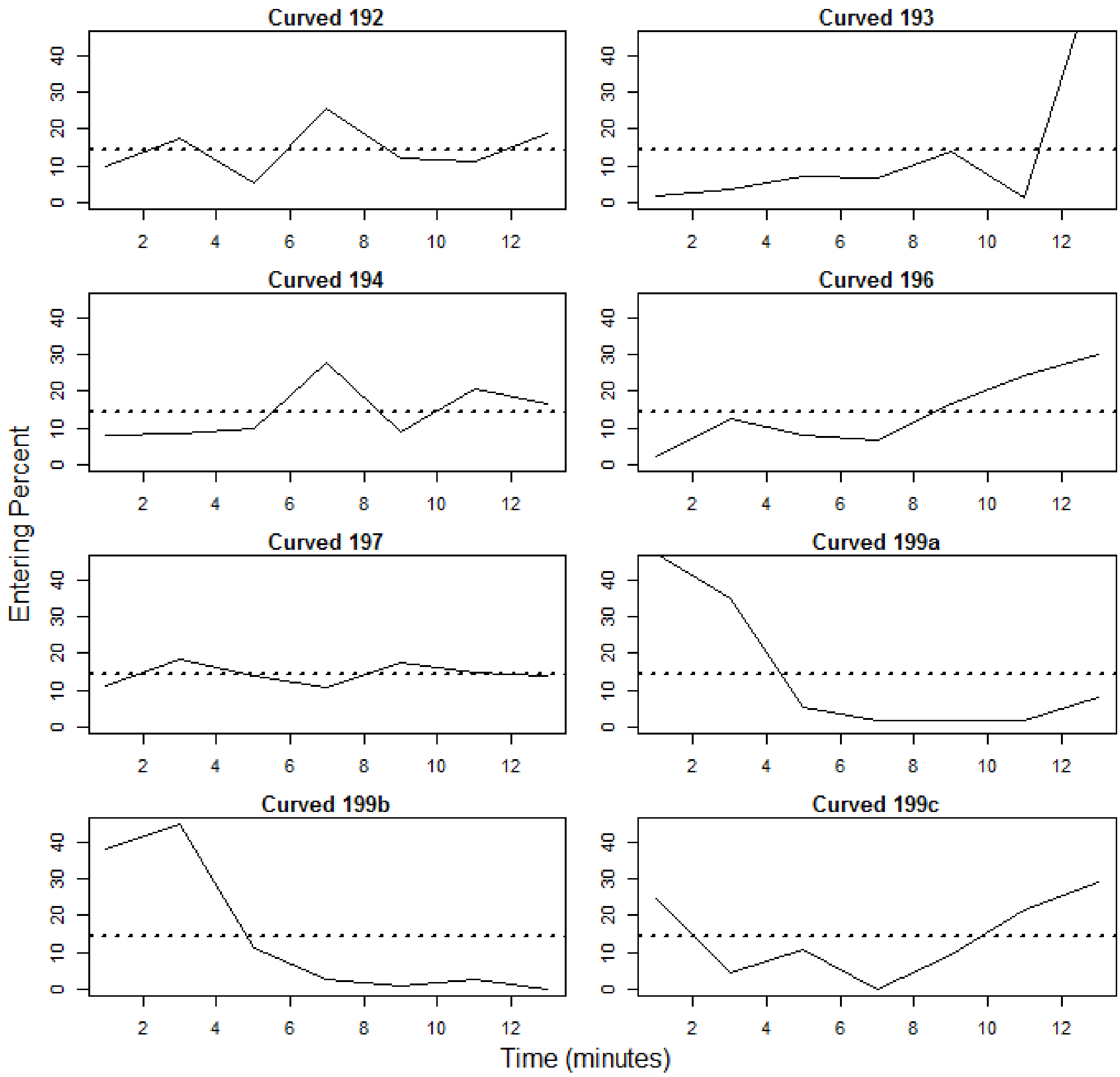

Figure 3.7. Proportion of mackerel from curved trawling passing through the DV unit over time, curved trawling method. The proportion is recorded every second minute during the last 14 minutes of each method of trawling. Dotted line at 14.3 % indicates how a steady flow of fish would appear (see for example “Curved 197”).

3.2.4 DELAY ANALYSIS

The delay analysis from hauls 197 and 199 shows that mackerel uses 130-190 seconds to pass the 65 meters between where the GoPro cameras was placed at the 200 / 400 mm and the Deep Vision at the beginning of the codend (Figure

3.8). This was based on four different peaks in the pattern of fish passage rate over time, found in both GoPro and DV entrance rates. Assuming a water flow of 2.6 m sec-1 (5 knots), a passive object would be expected to use 25 seconds to cover this distance. In haul 197, a lumpfish (*Cyclopterus lumpus*) was traced from the GoPro camera to the DV unit. The lumpfish, which is assumed to be a passive object and showed no signs of swimming in the GoPro video, used 31 seconds from the GoPro camera to the DV unit. This is 24 % longer time than the predicated time of 25 seconds, and could be due to slowly swimming against the trawling direction or being slowed as it contacted trawl meshes while moving back in the trawl. The width of the DV based curves are wider than the GoPro based curves, which indicate that small groups of fish are getting more and more elongated during their travel into the trawl. The GoPro camera was mounted three meters ahead of the DV unit showed no noticeable aggregation of fish there, so it appears that the elongation is not due to fish accumulating directly in front of the DV unit.

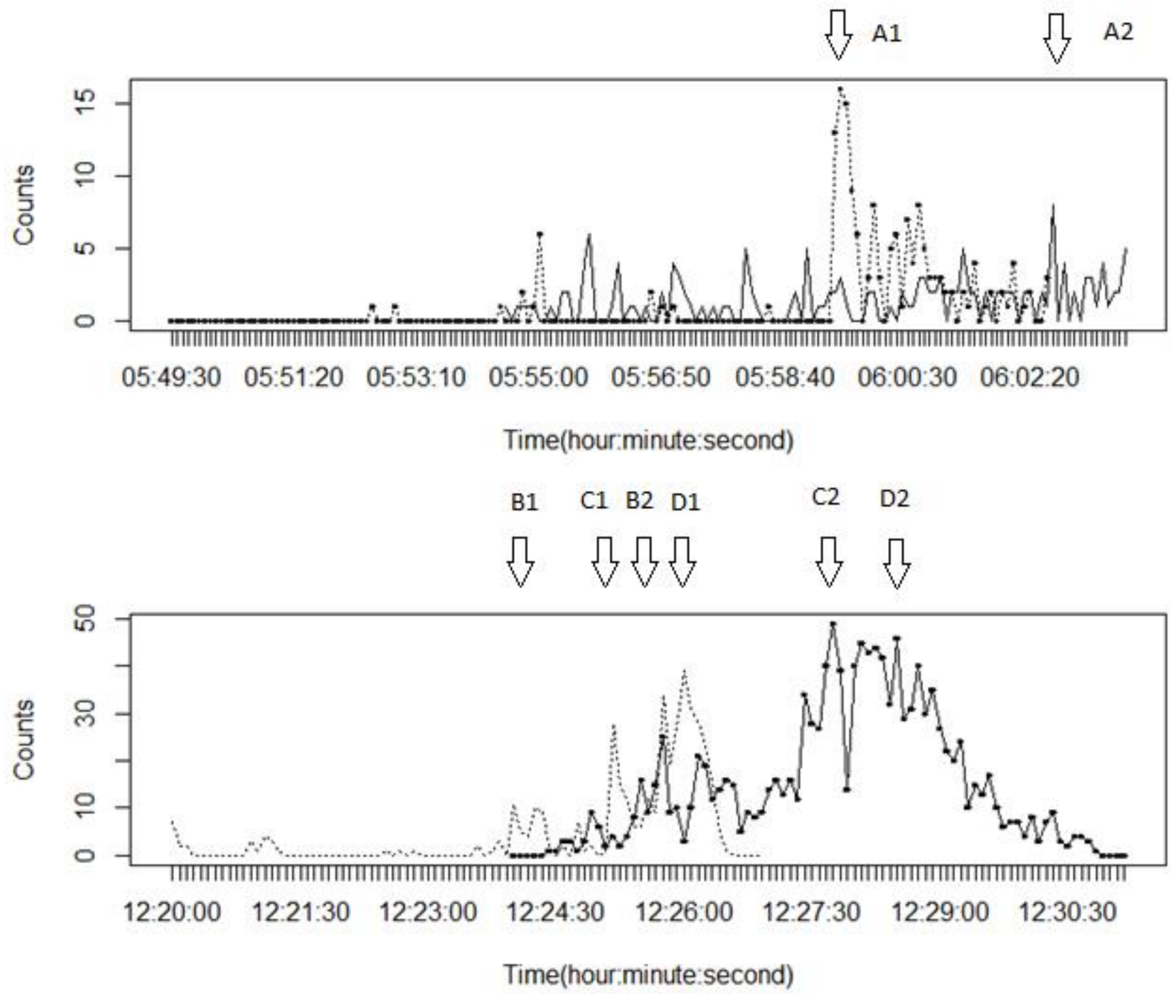

Figure 3.8. Number of mackerel entering every 5 seconds in both DV unit (solid line) and GoPro camera placed 65 meters in front of the DV unit (dotted line). Based on the peaks, mackerel uses 130 to 190 seconds to pass this distance. The arrows represent the peaks, labeled by letter (peak ID) and number (1 = GoPro, 2 = DV). The upper figure is from haul 197 and the lower figure is from haul 199.

3.3. TOTAL CATCH ANALYSIS (METHODOLOGICAL CRUISE AND IESSNS SURVEY)

3.3.1 CATCH WEIGHTS

The comparison between straight forward and curved trawling using the total catch data of mackerel showed no significant differences in total catches (kg mackerel) between the two methods ($p = 0.43$) based on a Wilcoxon signed- rank t-test. The straight forward trawling had a higher spread and a marginally higher median, as shown in Figure 3.9. The straight forward trawling had a 53% higher mean value (1551 kg) compared to the curved trawling (1016 kg), indicating a trend towards higher catches in the straight forward trawling. Non-parametric tests also did not show significant differences between the two trawling methods (Appendix C).

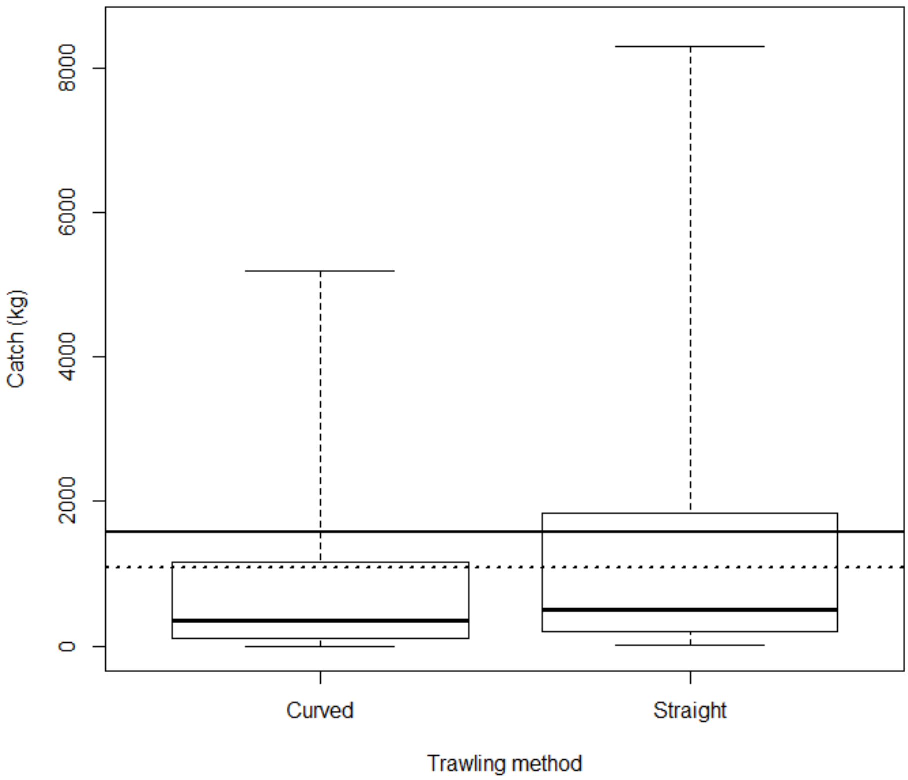

Figure 3.9. Catch weights from the IESSNS survey indicate that straight towing has higher mean, spread and a slightly higher median in catch than curved towing, but the difference is not statistically significant. The dotted line crossing both boxes represents mean catch weight in curved trawling and the solid line crossing both represents the mean catch weight during straight trawling. The solid lines within each box represent median values.

3.3.2 LENGTH DISTRIBUTION (TOTAL CATCH DATA)

A comparative analysis of the length distribution from total catch data in curved and straight forward trawling showed no significant differences when all of the fifteen comparison were tested in a combined test (p = 0.10, Kolmogorov-Smirnov test). However, this is a low p value and could indicate a trend towards smaller fish caught during curved forward trawling (Figure 3.10).There was a significant length difference in ten out of fifteen stations when they were analyzed individually using a Kolmogorov-Smirnov test (see Appendix D). Four of the hauls (IESSNS survey locations 9, 10 and 12 (Table 2.4) and methodological cruise station 205-206 (table 2.3)) had significant smaller fish in the straight forward trawling, while IESSNS survey locations 3, 4, 5, 8 and 11 (Table 2.4) had significantly smaller fish in the curved trawling. Methodological cruise station 3-4 also had a statistically significant difference in length distribution, but here it is hard to determine which trawl technique had the smallest fish. Contributing to the difficulty is the fact that the total catch in one of the comparative hauls was just 60 fish, so its length distribution is less well defined (Table 2.3, haul 3).

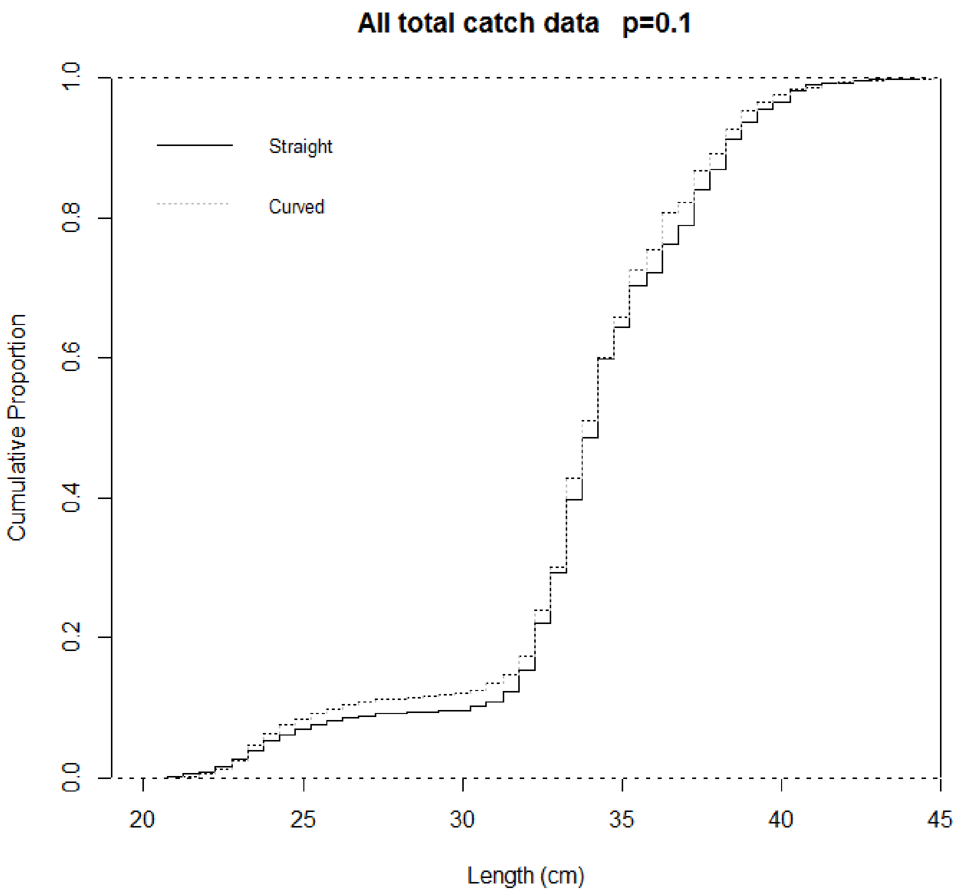

Figure 3.10. Cumulative distribution of all total catch length data during straight forward and curved trawling. The p values represent the difference between the length distributions in the alternating pairs (Kolmogorov-Smirnov test).

3.4 COMBINED METHODOLOGICAL CRUISE AND IESSNS SURVEY ANALYSIS

3.4.1 COMBINED COMPARISON BETWEEN STRAIGHT FORWARD- AND CURVED TRAWLING

The different sampling method made it hard to combine the total catch data and the count data in a statistical way. However, a binomial test was possible. The straight forward trawling had higher catches or counts in 21 out of 35 comparisons (Figure 3.11) but the results of the binomial test indicated that this was not a statistically significant result (p = 0.2).

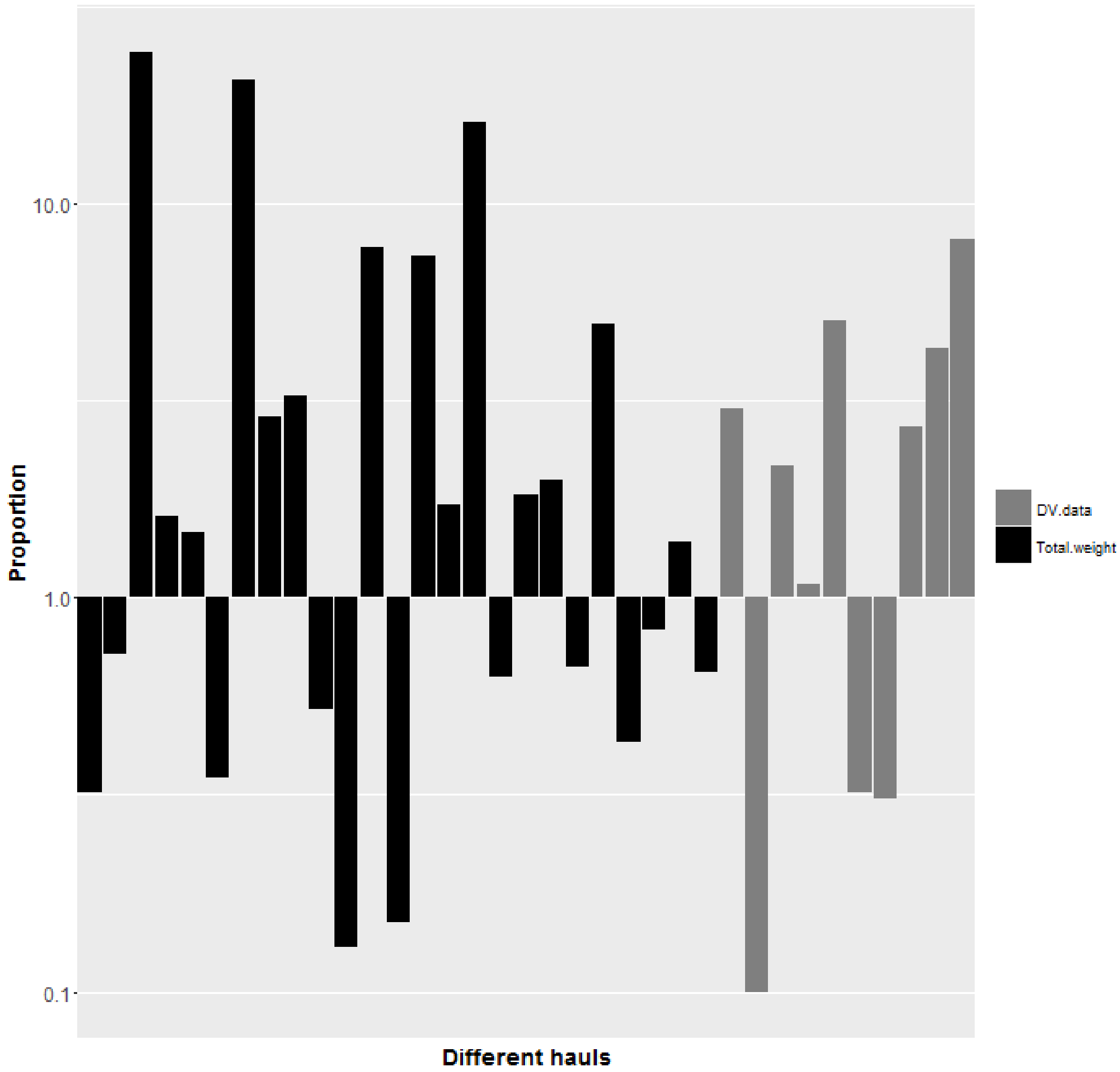

Figure 3.11. Catch proportions (straight forward / curved trawling) of the total catch and DV count data comparisons. Proportions > 1 represent comparisons with higher catches or counts with straight forward trawling and proportions < 1 indicate greater catches or counts with curved trawling.

3.4.2 COMBINED LENGTH DISTRIBUTION (DV AND MEASURED CATCH)

A binomial test based on the number of comparisons which had statistically significant differences in length distributions showed a near even split between whether the difference was for larger or smaller individuals ($p = 1$). This indicates that there is no difference between the size of fish captured in curved and straight forward trawling. More detail is provided in Appendices B and D.

4 DISCUSSION

No statically significant differences were observed in either catch amounts or length distributions between straight forward and curved trawling in this study. Although this is a "negative" result, it is interesting because curved trawling is believed to reduce avoidance behavior. It also suggests that the trawling operations during the IESSNS survey can be simplified by switching to the straight forward method without affecting the surveys outcome.

4.1 SHORTCOMINGS WITH DATA COLLECTION

The main concern with regard to the data collection was the time delay between the compared alternating (straight forward and curved) trawl hauls. When total catch data were collected during the IESSNS cruse, the time between the hauls was from two to three hours since the trawl had to be heaved, emptied, and set back out between hauls. This raises the question whether the hauls are strictly comparable or not. Deep Vision (DV) count rates from the methodological cruse also had a difference in time, but it was much less at 30 to 45 minutes. Although DV count rate seemed to be better fitted for comparison, it is not a perfect analysis due to the time consuming analysis the DV data required when compared to the relative quick method of measuring total weight data collected in the total catch analysis. Another problem is uncertainty in species determination, especially in the GoPro videos, but also sometimes in the DV unit pictures. In some of the pictures and videos, individual fish were unfavorable oriented such that the species determination was based entirely on body shape, and not color and other species specific traits. Nevertheless, it is hard to imagine an experimental setup that would have less offset in biases, especially concerning time and space, than using the DV unit.

One option for an experimental setup could be to conduct parallel trawling with two vessels in the same area at the same time, although this would introduce other potential sources of error including vessel and gear effects due to different noise levels in different vessels, different captains operating the vessels differently, etc (Simmonds and MacLennan, 2005; Nøttestad et al., 2016a). Although the vessel analysis did not show any significant vessel effect at the 0.05 level, the low p value ($p = 0.09$) suggest that a difference may in fact exist. In addition, the data was collected during conditions with natural light (day, dawn and dusk), but trawling in the IESSNS survey also occurs at night. This could affect the avoidance behaviour in mackerel, and lead do difference in catchability. For Norwegian spring spawning herring, vessel avoidance is particularly strong during dusk (Vabø et al., 2002) and Baltic herring have been shown to have a much stronger gear avoidance during day (Suuronen et al., 1997).

An abiotic factor that might influence catchability is temperature, which is believed to have several effects on fish, such as swimming capacity (Hurst, 2007), swimming speed (Dickson et al., 2002), size distribution (Nøttestad et al., 2016a), geographical distribution (Jansen and Gislason, 2011; Astthorsson et al., 2012), predator avoidance (Reynolds, 1977). However, temperature is not included in this thesis. Furthermore, mackerel are shown to be tolerant to a wide range of temperatures (6-25ºC) during summer in the Nordic seas (Nøttestad et al. 2016b), suggesting temperature to be of minor importance to the main results.

Combing the four types of haul data (table 2.1) was somewhat cumbersome, but was done in order to increase the number of comparisons between curved- and straight forward trawling and to get a greater spatial and temporal range. No statistically significant differences in methods were found, but a p value of 0.11 is close to significant. Another potential source of bias is the lack of consistency with regard to which trawl method (curved- and straight forward trawling procedure) was used in the start of the alternating trawl hauls, but the p value (0.34) indicates the impact is far from statistically significant. Although no significant difference was found, future studies should keep to one method of data collection with a 50/50 distribution of starting with curved and straight forward trawling and in addition try to reduce the differences in time and space between the haul pairs. This should be considered for the upcoming IESSNS survey in July-August 2016. Despite the greater amount of time required to analyze the data, DV unit count rate is the recommended sampling method due to the shorter interval between comparisons. If the IESSNS survey chooses not to change the trawling method due to lack of sufficient proof, to high spread in the data or number of comparative hauls, a new methodological survey is recommended. Such a survey should at least collect 70-80 DV hauls, but based on a review of the power analysis (Appendix E), the ideal number of hauls is higher. Alternatively, there could be collected around 30-40 additional pairs of hauls comparing total catch weight where the time between the alternations is kept to a minimum. Such data could easily be collected during the IESSNS survey.

4.2 CATCH COMPARISON: STRAIGHT- FORWARD AND CURVED TRAWLING

The comparison analysis showed no significant differences in total catch between the two methods of trawling. As a result, based on the main results from this study it is recommended to change the current IESSNS methodology from curved to straight forward trawling. Changing the trawling methodology could lead to a break in the time series, so further investigations and more comparisons might be needed before drawing a final conclusion. However, since the IESSNS is a relatively new cruise it makes most sense to make any change soon before a greater time series is built up using the curved trawling technique.

The lack of difference was surprising but can be explained by the distribution, density and behaviour of mackerel during the summer feeding season when the data was collected. Mackerel and other pelagic fish species have been shown to prioritize feeding over antipredator behaviour during this time of year (Fréon et al., 1993; Nøttestad et al., 1996; Nøttestad et al., 2016a). The mackerel could be less affected by noise, vibration and visual stimuli from the vessel and gear at this time of year, resulting in no significant difference between the two trawling methods. Another reason could simply be that the mackerel respond to the vessel, but calm down, started feeding again and resume natural behavior and distribution between the time the vessel passes and the trawl arrives. At the standard trawling speed, it takes 135 seconds between when the vessel passes and when the trawl doors arrive. The time is probably longer for free swimming fish, due to the herding effect which generally makes pelagic fish swim along with the vessel's direction (Misund and Aglen, 1992).

Both of the trawling techniques have potential drawbacks and the main drawback during curved trawling is believed to be asymmetric and more variable trawl geometry compared to straight forward trawling. This is a result of sometimes significant trawl door depth differences recorded during towing (John Willy Valdemarsen, personal communication). Asymmetry in the door depth and trawl geometry which could create escape routes for the fish and differences in warp and trawl vibration between the two sides of the trawl, altering herding effect and possibly increasing fish fear response including the likelihood that they will escape over, under and on the sides of the trawl wings and underneath the ground rope. Similar effects were found in other studies on several species of pelagic fish (Misund and Aglen, 1992; Misund et al., 1999) and the importance of trawl geometry is shown by the expensive measuring systems commercial fishermen by to monitor the trawls geometry to make constant adjustments in an attempt to keep the trawl symmetric in order to optimize catching efficiency. Noise is also known to radiate from the vessel and the noise has a characteristic butterfly wing like noise shape from the vessel bow (Misund and Aglen, 1992; Simmonds and MacLennan, 2005), with a sound maximum on the side of the vessel. This could impact pelagic fish and result in an increase in avoidance behaviour on the side of the vessel since fish has been observed to search for low level of noise (Misund and Aglen, 1992). Catches when trawling in a curved manner may also be reduced because of increased escapes through the very large (up to 16 m) meshes in the front portion of the trawl, especially on the starboard side of the trawl. This is due to a port side approach of the gear, which leads to a starboard preference in the swimming direction (Misund and Aglen, 1992). Furthermore, the limited underwater visual range, which is assumed to be maximum 40 m (Tyler, 1967), means only a portion of the fish and maybe only one individual actually sees the large meshes at the front of the trawl and the rest just follows the initiators response and do not actually see the trawl before later. In addition, the curved path of the trawl could lead tired and/or slow swimming mackerel to simply pass out through the large meshes in the front portion of the trawl. However, since the turn is only 5 degrees, the magnitude of the effect might be low and equivalent to abiotic factors which equally effects bout straight forward and curved trawling, as ocean currents.

The main concern around the straight forward trawling is increased avoidance behavior due to exposure to visual and sound stimuli from the wake, vessel and the propeller whose cavitation, is the primary source of vessel noise (Ona and Godø, 1990). The propeller, together with the rest of the vessel, could also scare fish away even before the vessel reaches the fish. Avoidance behaviour due to diving, which is a common avoidance behaviour (Misund and Aglen, 1992), may also be higher during straight forward trawling compared to curved trawling since the strong stimulus of the vessel passes directly over. However, zero mackerel was observed through the DV unit in the deeper haul (195) conducted with the headline at 30 m depth during the methodological cruise. Diving behaviour could, however, vary depending on conditions such as depth of the thermocline.

Although no significant differences were observed between the two different trawling methods, there was a trend towards higher catches in the straight forward way of trawling. This is unexpected since the curved trawling technique was developed to reduce avoidance, increase catch rates and give a better and more representative description of the fish stock. If a valid trend exists, it could be a result of pure coincidence, or a combination of several different reasons working together and could differ due to changes in natural conditions and fish behaviour. The most plausible explanation is a result of reduced predator avoidance as a result of the summer feeding season (Nøttestad et al., 2016a), leading to insignificant vessel avoidance and a slightly worse curved trawling performance due to sub-optimal trawl geometry. However, the trend is small and even if it is true it supports the recommendation to switch to straight forward trawling.

4.3 LENGTH COMPARISON: STRAIGHT- FORWARD AND CURVED TRAWLING

No statistically significant difference was found between length distributions in curved and straight forward trawling when comparing all of the hauls together (DV and total catch separated). This is an important result because a difference in length distributions between curved and straight forward trawling could lead to biased abundance estimation leading to inaccurate assessment advice due to wrong and skewed age structure. It is especially important if the trawling procedure is going to change because this will have an impact on the annual age structure development. This is not to say that the surface trawling technique is not biased in the sizes it captures, just that there is no difference between trawling straight forward and in a curve. Size distribution was examined in greater detail by looking at each of the alternating haul comparisons individually and no consistent differences were found. In the comparisons where differences in length distributions were statistically significantly, it was equally likely that the larger fish would be in the curved trawling hauls or the straight forward ones. These results are consistent with the lack of change in age structure results from the mackerel survey when it switched from straight forward trawling with a commercial pelagic trawl to trawling with the Multpelt 832 in a curved trawling procedure between 2011 and 2012 (Nøttestad et al., 2016b). However, due to the importance of length distribution and low p values in the length distribution analysis on all of the DV data and all of the total catch data combined ($p = 0.055$ and $p = 0.1$), the collection of additional data is recommended.

4.4. MACKEREL DISTRIBUTION ANALYSIS

Mackerel seems to enter the trawl in small and rather loose aggregations and passages of individual fish were rare, indicating that mackerel has a certain shoaling and aggregation behavior during the summer feeding season. Similar observations were found in the GoPro cameras further in front in the trawl and in the delay analysis (Figure 3.8). There were also hauls with zero catch (removed from the analysis), which could support the theory about an aggregating behaviour. This suggests that the swept area method may lead to a certain amount of bias in the final assessment, but its effect is probably low compared to other sources of biases such as escape during low trawling speed (especially during deployment and hauling of the trawl), time series inconsistency and variation of survey coverage as well as inconsistency in trawl and trawling procedures, etc. (Nøttestad et al., 2016b). Previous studies as (Godø et al., 2004; Iversen, 2004; Nøttestad et al., 2016a) have concluded that NEA mackerel have reduced shoal forming behaviour during summer feeding season compared to the other seasons during the year. Therefore, this study suggests that the swept area method as a suitable method for the IESSNS survey and furthermore to be used for abundance estimation of NEA mackerel into the assessment. There are however, some assumptions, uncertainty and limitations in this analysis

The restricted geographical area from where the data was collected is a limitation of this study. The location does not necessarily represent the whole mackerel distribution area. The analysis also uses entering percentages, which could be misleading since it does not take number of fish which enters the DV unit, into account. If the entrance of mackerel is low, the fish could enter within a short period of time, giving the impression that mackerel distribution in the sea is heavily aggregated. Furthermore, the analysis assumes that the observed patterns of mackerel passing through the Deep Vision reflect their distribution as they entered the trawl (fish entering the trawl alone do not form groups inside the trawl and fish entering in groups do not spread out inside the trawl) The delay analysis showed, however, a wider curve in the DV observations, which indicates an elongation of the fish aggregations the closer the fish swim towards the codend. Such an effect will give the impression that the mackerel stock is more evenly distributed, which is a drawback with the analysis. It is however reasonable to believe that vessel and gear avoidances together with the trawl constriction itself leads to aggregation of fish. Such aggregating effects is found in several studies and an example is vertical compression and diving responses of midwater schools between the vessel and the trawl (Taylor, 1968; Misund and Aglen, 1992). This leads to more aggregation and herding of fish, which could create an impression that mackerel is more aggregated than they are in their natural state before entering the trawl.

Although, some elongation occurs, it is not enough to have a huge impact on the distribution analysis and no such effect is found in the size over time analysis (Appendix F). Vessel and gear avoidance leading to aggregation is however more concerning, but it is hard to estimate the actual impact of such an aggregation. However, for assessment purposes related to swept area technique, these uncertainties are probably low, compared to other sources of biases such as escape of fish not behind the fish lock during low trawling speed during deployment and heaving of the trawl, time series inconsistency and variation of survey coverage as well as inconsistency in trawl and trawling procedures, etc. (Nøttestad et al., 2016b).

4.5 DELAY ANALYSIS

The fish seem to flow through the trawl in a relative constant manner, probably with an increased swimming behaviour along the trawling direction as the trawl constrict and this may lead to some elongated of fish aggregations. According to video collected with the GoPro camera in front of the DV unit, no noticeable aggregation occurred as a result of the DV unit. However, the elongation together with other limitations with the delay analysis will be a source of some error in all the DV analyses performed during this study, particularly the distribution analysis. The main limitation with the delay analysis is the estimation of the GoPro entrance rate. Only 31 -55 % of the fish observed in the DV unit were observed in the GoPro camera. This means a majority part of the fish are outside the vertically oriented GoPro camera's field of view. It is also hard to determine species through the GoPro camera, due to a low location of the camera which only detects silhouettes of the fish against the bright water surface. This made it necessary to locate almost homogenous mackerel shoals for the analysis. A small proportion of the fish were not counted in the GoPro camera, assuming that the fish was a herring based on the slimmer body shape and that the fish passed quickly due to low swimming speed or exhibited other swimming behavior characteristic for herring such as erratic swimming near the trawl meshes in what appeared to be a search for escape.

The wider shape of the DV graph is assumed to indicate aggregation of fish. This is probably due to decreasing width of the trawl that forces the fish closer together. To maintain distance between the fish, aggregations must elongate in the direction of trawling. This behavior could be increased in response to the flashing lights mounted inside the DV unit. In addition, because of an increase in swimming capacity with an increase in fish size (He, 1993), the smallest fish in a small shoal should be expected to pass first and the larger fish afterwards. However, the size over time analysis indicates no such effect (Appendix F). It could also be a result of high fluctuation of DV flowrate (Appendix G). This could be a result of several shoals are piled together over the time period, leading to a fading of such effects in the data or relatively short time interval (145-555 seconds), which might not be long enough to show such a pattern. As mentioned above, studies have observed vertical compression and diving response of midwater schools between the vessel and the trawl (Taylor, 1968; Misund and Aglen, 1992). This could lead to more aggregation and herding of fish, with groups of different sized fish clumping together. The difference in size leads to difference in swimming capacity that elongates the aggregation. This could also influence of the passage rate. The natural schooling behaviour could force small fish to swim faster than they normally do, or make large fish reduce their swimming speed. Furthermore, fish tend to school with individuals of similar size, reducing the variation of size inside a particular school of fish (Pitcher et al., 1985; Hemelrijk and Kunz, 2005).

4.6 CONCLUSION AND RECOMMENDED FUTURE INVESTIGATIONS

No significant difference in catch or length was found between the two different trawling methods; straight forward and curved trawling. However, the dataset is somewhat limited so further investigations are recommended since the result suggest the trawling technique in the IESSNS survey should be changed. DV count rates are considered the best way of collection additional data due to the efficient and accurate data it provides as well as the low time between comparisons and the possibility to conduct several alternating pair hauls within a short time span (up to five alternating hauls within three hours). However, DV data requires a huge amount of analysis, so development of a robust method to reduce the analysis time is recommended.

A possible solution could be to count the number of fish in every tenth picture in the DV unit (two seconds) and make a ratio between these every ten pictures and fish swimming through within a minute. This would save technicians or scientists a lot of time. Another option is to introduce image analysis systems with auto counting and recognition of species. There exist several studies on these kind of systems (Spampinato et al., 2008; Spampinato et al., 2010; Shortis et al., 2013), and it should be possible to implement DV pictures or GoPro videos in such programs. It might also be possible to introduce a multi-frequency echo sounders to collect data and separate species inside the trawl and then count the fish with the right acoustic signature (Korneliussen and Ona, 2003; Korneliussen, 2010). Furthermore, a combination of acoustic data and videos inside the trawl could be possible using a so called acoustic-optical system, which combines an acoustic system with a low-light camera to verify fish species (Ryan et al., 2009).

Alternatively, further total catch comparisons could be carried out where the time between the alternations is kept to a minimum. Additional data from either DV count rates or total catch comparisons could easily be collected during the regular IESSNS. The best possible trawling design while comparing the different trawling methods uses one vessel to get rid of potential vessel effects and conducts the hauls in a range of different temperatures and different locations which represent the geographical area sampled during the IESSNS survey. The hauls should also be 50/50 distribution between starting in curved trawling and straight forward trawling. Future studies should also sample randomly through day and night, because this could have an effect on catchability.

This study considers mackerel distribution to be sufficiently uniform distributed to use the swept area methodology as a way to estimate abundance of NEA mackerel. However, any future analyses should reduce the intervals were fish was counted and the spaces without data between the counted minute intervals should also be reduced or removed. An example setup could consist of a continuous interval where entrance of fish is recorded every 10 second, or alternatively every other 10 second. Such an experiment could be conducted during pair-trawling, where two vessels pull the trawl (one pulling the port warp and the other the starboard warp) and the trawl passes in the gap between the vessels. This should reduce avoidance effect from the vessel and then better describe the natural distribution pattern.

A new delay analysis should contain of time periods from both curved and straight forward trawling. It could also be an advantage to choose an area without herring, since this makes the GoPro analysis much easier. The fish size over time analysis would be improved by increasing the time span of the analysis and including hauls from both of the trawling methods.

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6. APPENDIX

APPENDIX A ADDITIONAL STATISTICAL ANALYSIS FOR ENTERING RATE COMPARISONS

Some difficulties occurred regarding the determination of the DV count datas distribution. The distribution was skewed and therefore, most likely a Poisson distribution which was presented in the thesis. Wilcoxon signed- rank t-test was run as an additional test and it showed no significant differences ($p = 0.70$). Wilcoxon signed- rank t-test were chosen since it is a statistically non-parametric hypothesis test for comparison between two related or paired samples.

APPENDIX B LENGTH DISTRIBUTION (DEEP VISION)

A comparative analysis was done to compare the length distribution in curved and straight forward trawling. No significant differences were found between curved and straight forward trawling, when all of the ten length distributions for each trawling method were tested in a combined test (p = 0.055). There was a significant length difference in four out of eight hauls based on a Kolmogorov-Smirnov test (Figure B-1, Figure B-2). Two of the comparisons (197, 199ab and 199c) had significant smaller fish in the straight forward trawling, while the last (199a) had significantly smaller fish in the curved trawling compared to in the straight forward trawling (Figure B-2).

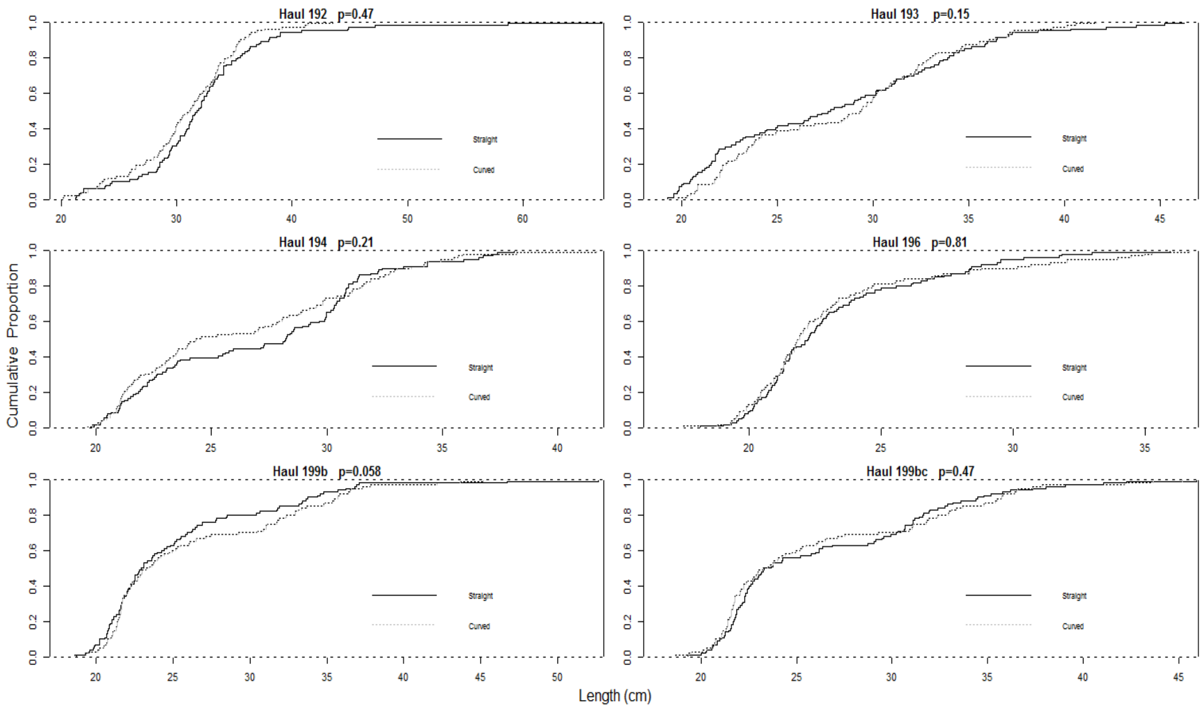

Figure B-1. Cumulative length distribution of all non-significant length distributions differences in the Deep Vision data (Table 2.2). Each line is based on the length distribution of 100 fish measured by the DV Software. The p values are results from a Kolmogorov-Smirnov test comparing difference between the length distributions in the alternating pairs.

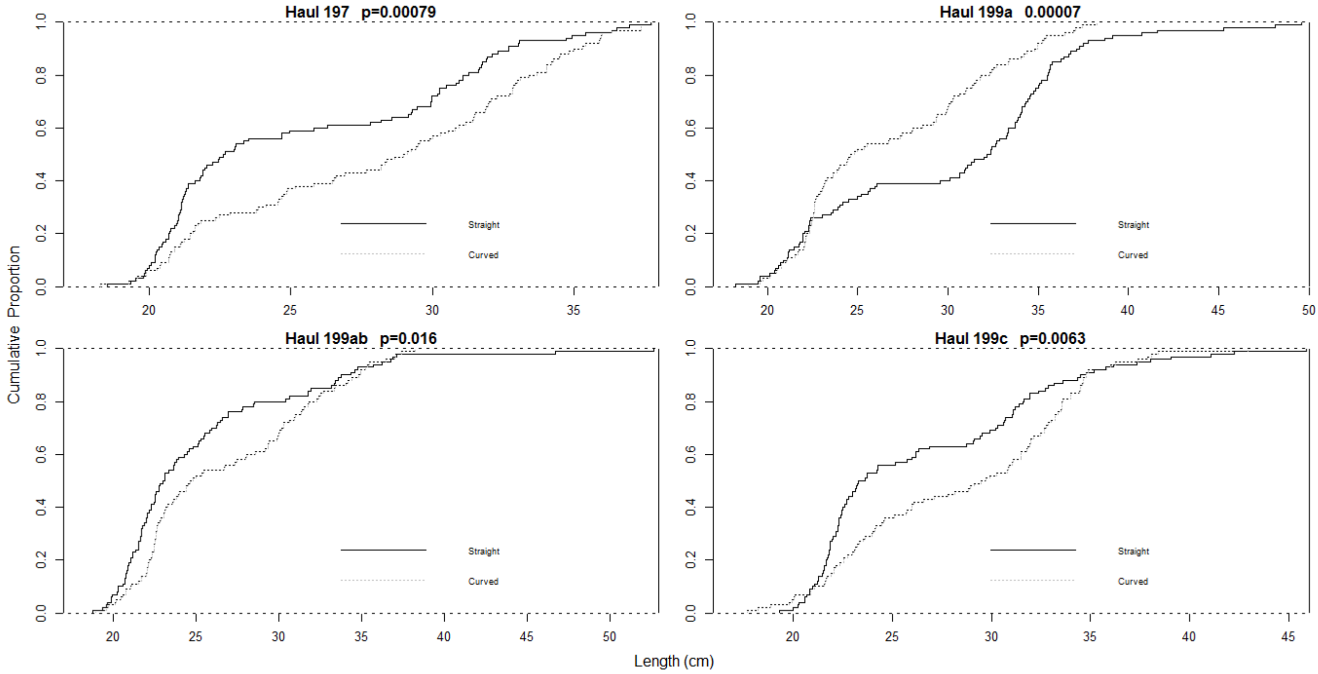

Figure B-2. Cumulative length distribution of all significant length distributions differences in the DV data (Table 2.2). Each line is based on the length distribution of 100 fish measured by the DV Software. The p values represent the difference between the length distributions in the alternating pairs (Kolmogorov-Smirnov test).

APPENDIX C ADDITIONAL STATISTICAL ANALYSIS FOR TOTAL CATCH COMPARISONS

Difficulties occurred during the determination of the total catch datas distribution pattern. Therefore, a non-parametric test between two related or paired samples was presented in the study. However, total catch data is usually assumed to be normal distributed, so a paired t-test was run as an additional test ($p = 0.24$).

APPENDIX D LENGTH DISTRIBUTION (TOTAL CATCH)

A comparative analysis was done to compare the length distribution from total catch data in curved and straight forward trawling. No significant differences were found between curved and straight forward trawling when all of the twenty-four length distributions for each trawling method were tested in a combined test (p = 0.10). There was a significant length difference in ten out of fifteen hauls based on a Kolmogorov-Smirnov test. Four of the stations (locations 9, 10 and 12 and station 205-206) had significantly smaller fish in the straight forward trawling, whereas locations 3, 4, 5, 8 and 11 had significantly smaller fish in the curved trawling (Figures D-1, D-2 and D-3). The last station which had a significant difference was comparison 3-4 from Brennholm (Table 2.3), but it was hard to determine which trawl technique had the smallest fish due to large disruptive length distribution in haul 203. However, this station included haul 3 which only had length measurements form 60 fish due to a small which may have been insufficient to give a reliable length distribution.

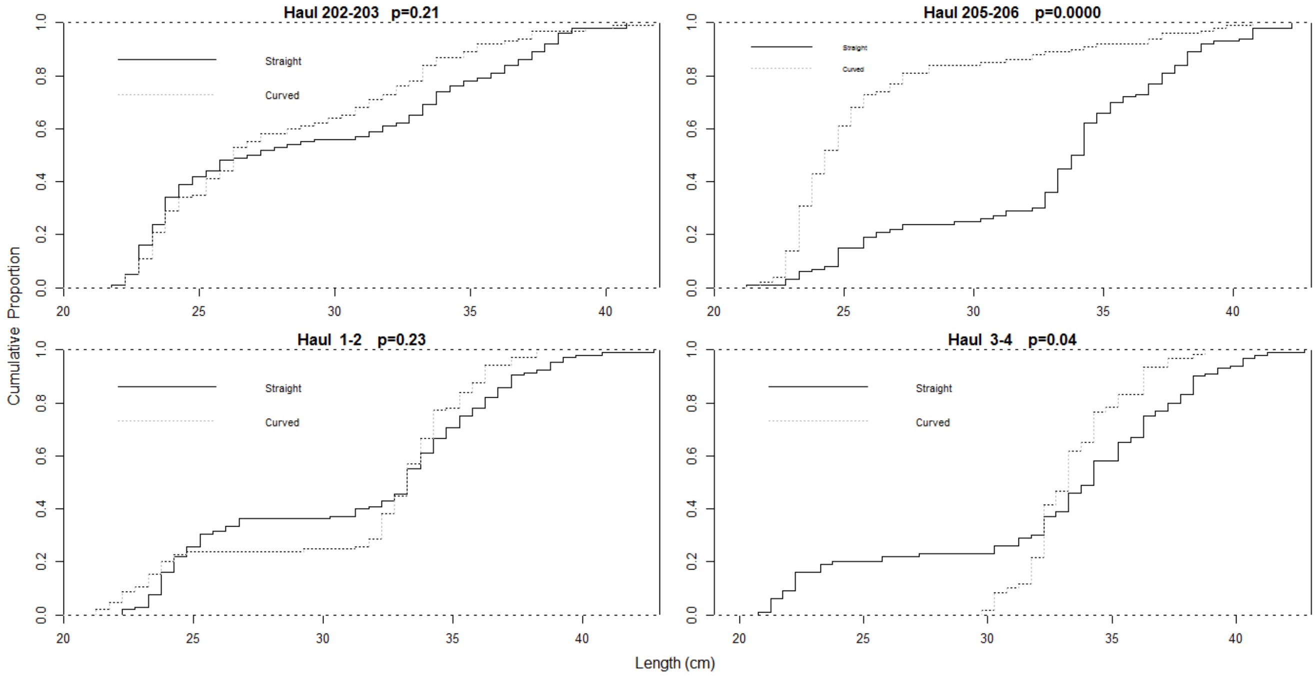

Figure D-1. Cumulative length distribution of all total catch analysis from the methodological cruise except 204-205 (Table 2.3). Each line is based on the length distribution of 100 fish measured by the DV Software. The p values represent the difference between the length distributions in the alternating pairs (Kolmogorov-Smirnov test).

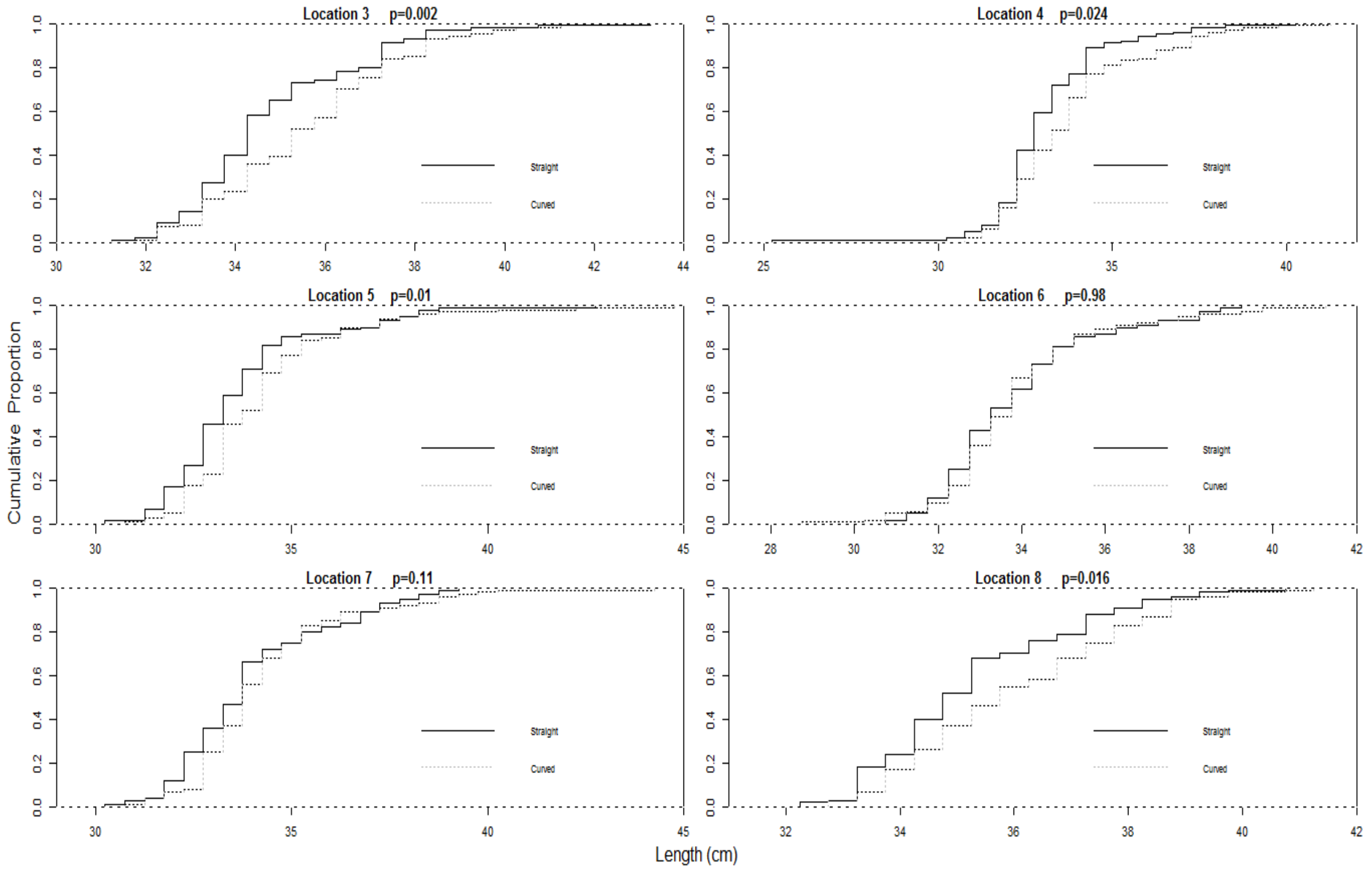

Figure D-2. Cumulative length distribution of all total catch analysis from Eros during the IESSNS survey (Table 2.4). Each line is based on the length distribution of 100 fish measured by the DV Software. The p values represent the difference between the length distributions in the alternating pairs (Kolmogorov-Smirnov test).

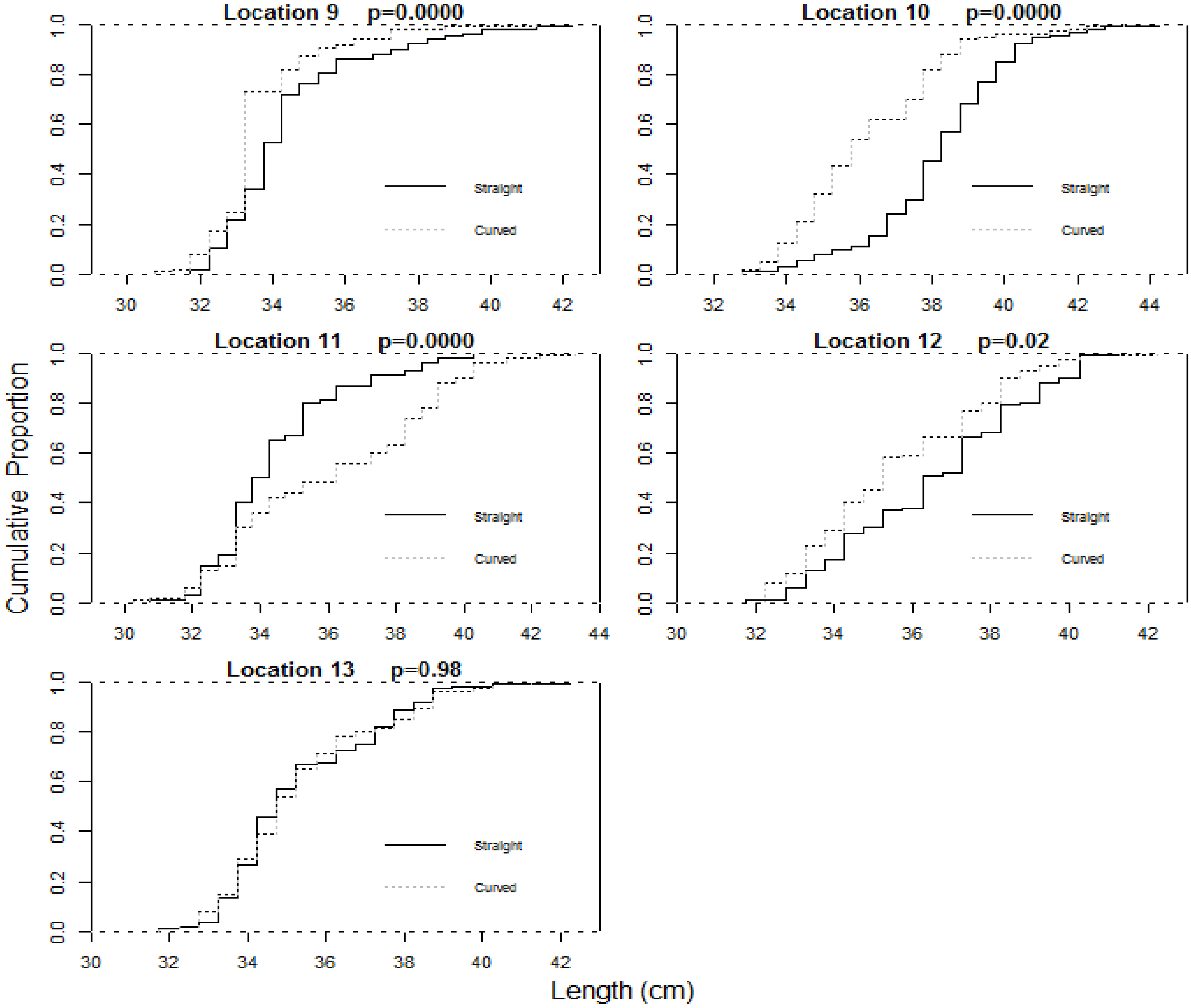

Figure D-3. Cumulative length distribution of the total catch analysis from Brennholm during the IESSNS survey (table 2.4). Each line is based on the length distribution of 100 fish measured by the DV Software. The p values represent the difference between the length distributions in the alternating pairs (Kolmogorov-Smirnov test).

APPENDIX E POWER ANALYSIS

The power of a test is the probability of rejecting the null hypothesis which for this study means the probability of a certain amount of samples showing a significant difference between the two trawling methods given the data analyzed. This thesis operates with 95 % confidence interval, which is also the probability applied for the different trawling methods analyzed in this thesis. Given these conditions, the count analysis based upon Deep Vision data needs 569 pared samples to have a 95 % probability of showing a statistical significant difference between the two methods. The high requirement of samples reflected in the results of the power analysis indicates a relatively little difference between the trawling methods (Figure 3.4). However, given the same requirements, total weight analysis only needs 66 pared samples. This is due to a high variance and a 53% difference in mean value, which reduces the number of samples to get high statistical power (figure 3.9). Plotted power analysis shows how the power increases with an increase in sample size (Figure E-1).

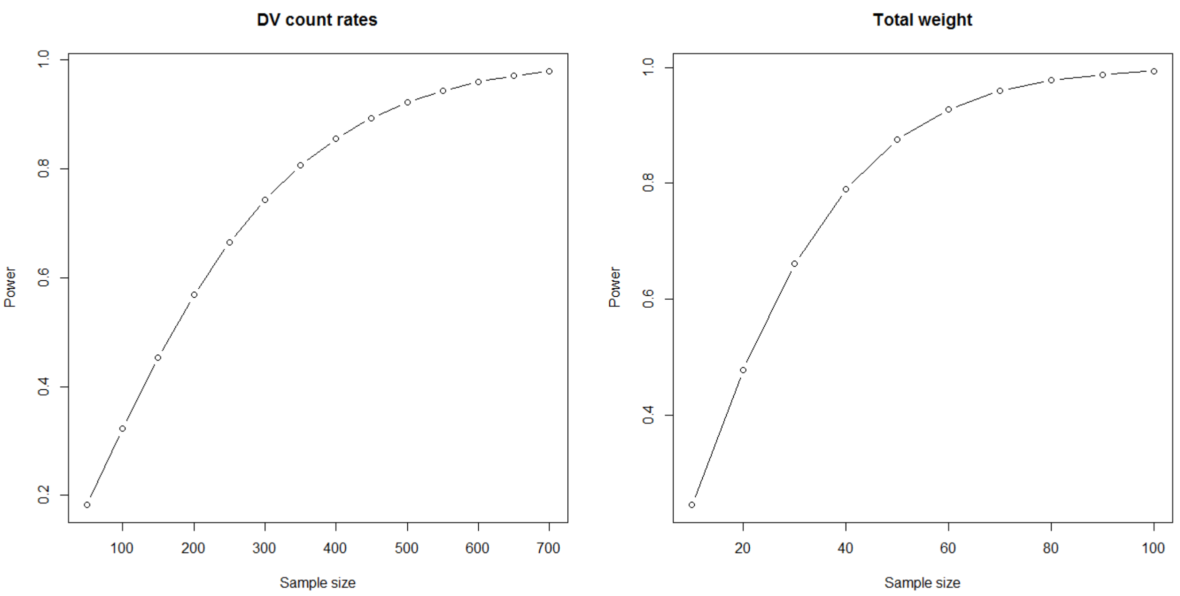

Figure E-1. Increase in statistical power with increasing sample size. The graph on the left side is from the comparison in the DV count rates data and the right graph is form the total weight data.

APPENDIX F SIZE OVER TIME

Analysis of fish length over time did not show any clear pattern indicating size related swimming capacity (Figure F-1). Linear model of average length as a function of elapsed time shows no significant relationship (R^2 = 0.002 (haul 193), 0.087 (haul 197) and 0.004 (haul 199)) However, the analysis follows several small groups of mackerel and the size structure within groups of fish is shown to be similar with greater variation between groups. The analysis was only run from 145 to 555 seconds, and this may be too short of an interval to detect differences in the length distribution over time due to swimming capacity. Furthermore, the analysis is only based on straight forward hauls and the result could differ during curved trawling.

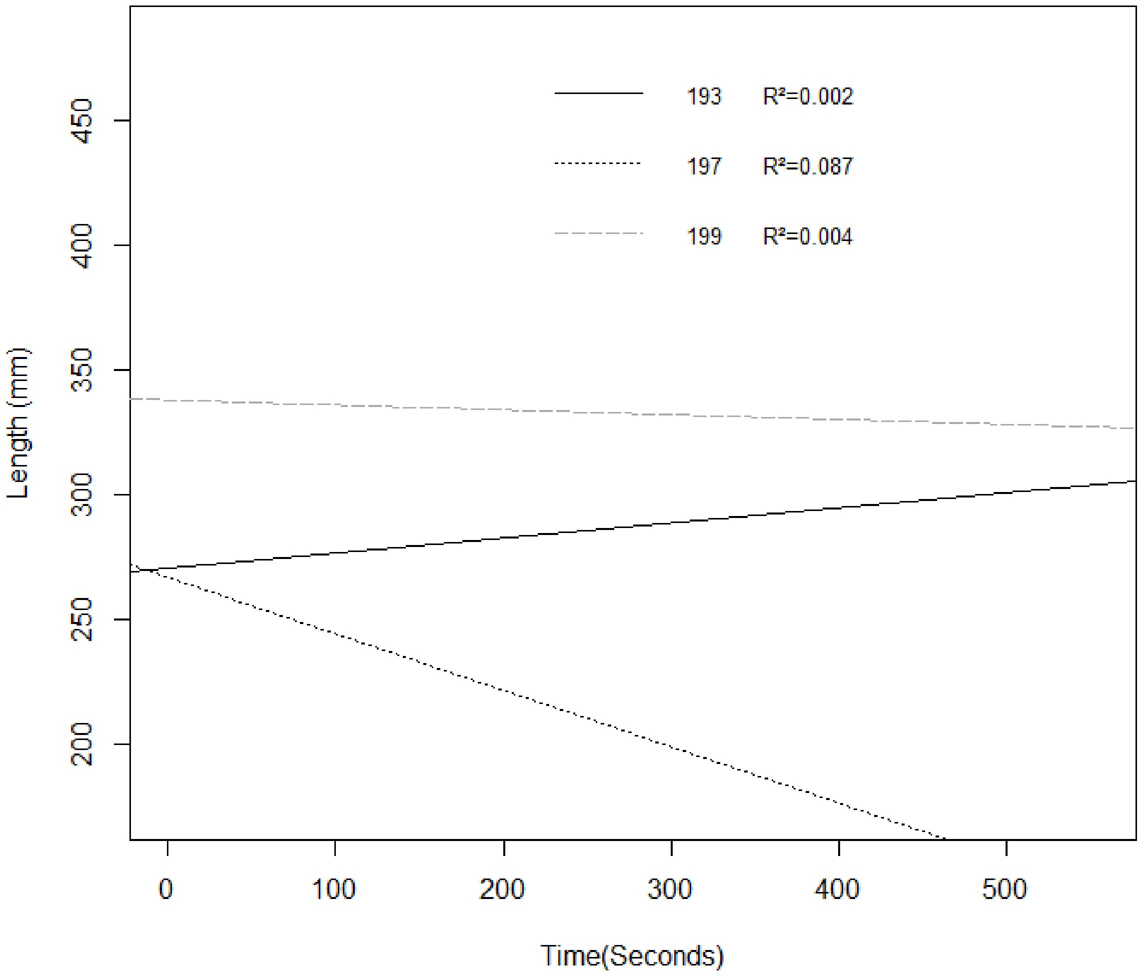

Figure F-1. Linear model of average length as a function of elapsed time for mackerel passing through the DV unit, hauls 193, 197 and 199.

APPENDIX G FLOW RATE IN THE DV UNIT

The water flowrate through the DV unit seems to be heavily reduced. The mean flow rate in the straight forward trawling was 1.6 m/s compared to 1.5 m/s in the curved trawling. However, a negligible difference between curved and straight forward trawling was found and is shown in figure G-1. The flowrate spread was almost the same in the different hauls and no statistically significant difference was found ($p = 0.63$, Anova). Even if the flow rates seem to be similar in the different trawling methods, the high spread indicates a high variation in flow rate thought the DV unit. The spread in the straight forward trawling was 0.4-2.4 m/s and curved trawling had a spread between 0.4 – 2.6 m/s. The large difference between the towing speed and the water flowrate in the DV unit could be due to measuring errors, actual reduced flowrate due to pressure wave in front of the DV unit, reduced jellyfish speed and last but not least flowrate reduction for objects which rea near the camera in the DV channel (Rosen, 2013).

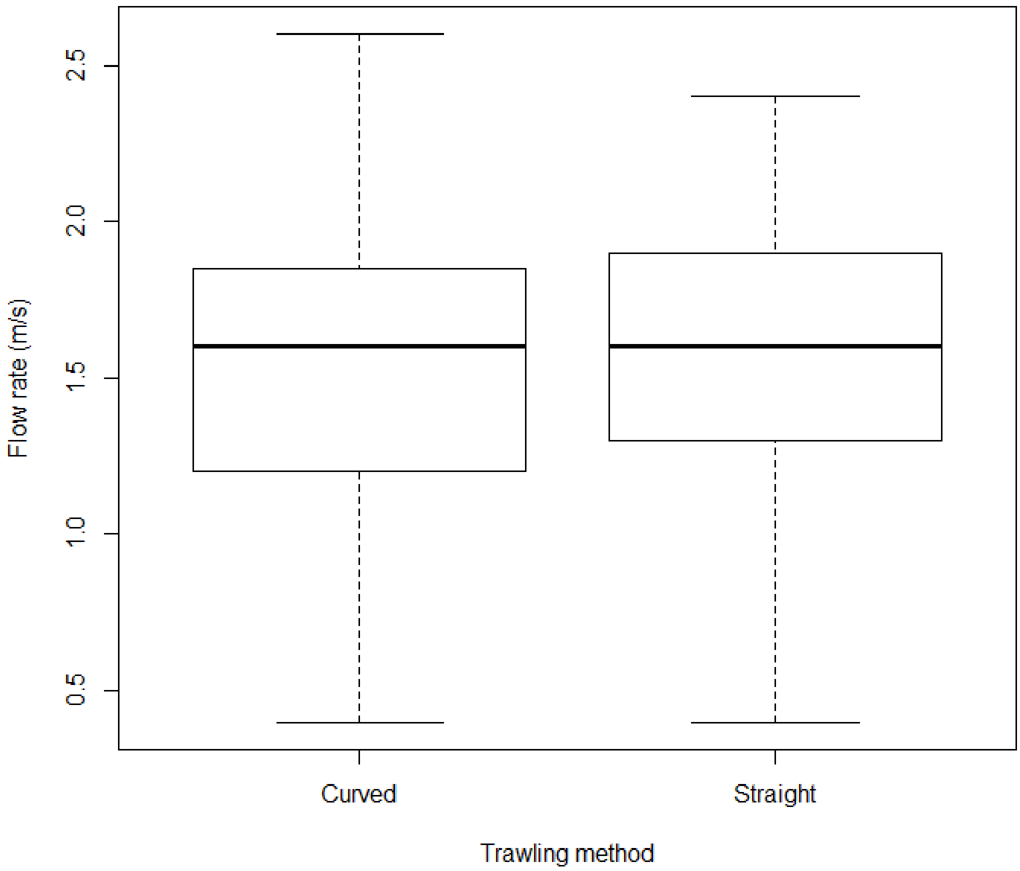

Figure G-1. Flow rate of passive organisms inside the DV unit during the different trawling methods. Trawling speed was 2.6 m sec-1 (speed over ground from GPS). The analysis was based on five samples in each method from each haul (40 samples per method), and the passive objects were jellyfish and small shrimps. There is no statistically significant difference between the two methods.