# Towards monitoring zooplankton and small pelagic fish in the Wadden Sea

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# Contents

# Summary

This report presents the activities and results from the ZKO Wadden Sea study "839.08.242 Acoustic surveys and plankton sampling" funded by NWO.
This pilot study consisted of two parts: (1) testing the possibility to mount a scientific echosounder on the TESO ferry between Den Helder and Texel to monitor the abundance of pelagic fish in the Marsdiep area and (2) testing the possibility to sample plankton by means of an Autonomous Plankton Sampler on board the ferry MS Vlieland between Harlingen and Vlieland. The tests with the installation of these systems are described. The study included also four reference hydro acoustic surveys, targeted on pelagic fish, in the Marsdiep in May and October 2010 and 2011.

Hydro acoustic data collection with an echosounder on the TESO ferry was not possible due to air bubbles causing noise and transmission loss. We expect that this can be solved in the future, by making special adjustments on the hull where the equipment is mounted.
The hydro acoustic surveys revealed the presence of high concentrations of clupeids in the Marsdiep, dominated by sprat (*Sprattus sprattus*). The summed biomass of Clupeids in the Marsdiep was estimated to be 613/369 tonnes in May 2010/2011 and 67/69 tonnes in October 2010/2011. The biomass of pelagic fish per water volume in October is approximately 20 times as high as the biomass of demersal fish per water volume as estimated from the DFS survey in autumn. The majority of the pelagic fish schools are found in the upper layers of the water column. Almost 50% of the fish is distributed in the upper 6 m. As the depth of the hull mounted transducer on the TESO ferry is 5 meter, it is to be expected that most fish will be missed. For future monitoring of pelagic fish it is therefore recommended to install a fixed installation at the bottom heading towards the surface.

An Autonomous Plankton Sampler (APS), based on the widely applied Continuous Plankton Recorder, was installed at the MS Vlieland, the ferry sailing from Harlingen to the isle of Terschelling. The efficiency of zooplankton collecting appeared to be sensitive to the water inlet system for which the necessary adjustments could not (for safety reasons) be implemented on the ferry. Different vessels were therefore used to further improve the APS, in particular the inlet system by using a gauze funnel of different sizes and sampling directions. An improved design was tested for robustness under offshore conditions, and a final design was used to collect samples in the Wadden Sea. The final design was able to collect different taxonomical groups of (meso)zooplankton, including copepods and larvae of zoobenthic species, in relevant quantities. In case the system would be implemented in monitoring, it is recommended to install the APS on board of a monitoring vessel. Further research should be dedicated to the catch efficiency of different species and groups of zooplankton.

# 1 Introduction

This pelagic ZKO monitoring, was an experimental study carried out as part of the ZKO monitoring program on the monitoring of pelagic fish and zooplankton. The ZKO program (Dutch National Ocean and Coastal Research Program or Zee en Kust Onderzoek, ZKO; www.nwo.nl/en/research-and-results/programmes/The+National+Ocean+and+Coastal+Research+Programme%E2%80%AC) has been launched in order to integrate fill gaps in current marine research, carried out by different Dutch scientific institutes. More specifically, the objective of the pelagic fish and zooplankton programme was to complement the existing but incomplete monitoring programme in the Wadden Sea (NIOZ fyke net catches) by providing information on the seasonal patterns in fish biomass, size structure and species composition of the pelagic fish assemblages as well as the seasonal fluctuations in abundance and species composition of zooplankton. As there is currently no experience with monitoring of zooplankton and pelagic fish in the Wadden Sea, the program is designed as a pilot.
The only existing monitoring on fish in the Wadden Sea area are the daily catches of the NIOZ fyke in the Marsdiep(Van der Veer et al., 2011). The value of this program for knowledge on pelagic fish is limited since the fyke catches for mainly large, straddling fish rather than school of small pelagic fish.

## 1.1 Pelagic fish assemblages

Coastal areas are presumed to be important nursery and feeding areas, not only for bottom-dwelling species, but also for pelagic fish. Although the influence of coastal habitats on survival, growth, and reproduction of marine species has been demonstrated, the absolute value of these habitats to their population dynamics have rarely been quantified (Vasconcelos et al., 2014). Coastal areas provide the habitat used by fish during a particularly vulnerable life stage. At the same time these areas are often intensively exploited by diverse human activities and have been degraded in recent times (Airoldi and Beck, 2007; Beck et al., 2001).
Small pelagic fish are usually only studied in areas with a bottom depth over 20 m. A main reason for this lack of studies in shallow coastal waters is the difficulty to apply traditional acoustic methods during acoustic surveys in these often turbid waters.
The Dutch Wadden Sea is Europe's largest estuarine area. The Wadden Sea and adjoining coastal area, both Natura 2000 sites, are used by juvenile fish that later in life recruit to commercially exploited adult populations (herring *Clupea harengus*, pilchard *Sardina pilchardus*, anchovy *Engraulis encrasicolus*, sandeel *Ammodytes* sp.). Older life stages of some of these species stay in the shallow waters for feeding. Still, in the past decennia main research focus was put on demersal fish, caught with bottom trawls (Bolle et al., 1994; Tulp et al., 2008; van der Veer et al., 2011).
Besides it's commercial importance, pelagic fish also play an important role in the coastal ecosystem as a main prey species for large, local concentrations of waterbirds, both in the breeding and overwintering period. Several tern species (Sternidae) that form large colonies on the Wadden Sea islands feed on pelagic fish during their breeding period to provide for their chicks and for self-maintenance (Daenhardt and Becker, 2011; Daenhardt et al., 2011). They catch small fish striking the water in shallow dives or skimming the surface. During wintertime grebes (*Podiceps cristatus*) and auks (Alcidae) spend several weeks up to months along the Dutch coast, where they feed on small pelagics (Couperus and Tulp, 2005). In contrast to terns, grebes and auks catch their prey while diving. The fraction of small pelagics available to both diving and non-diving birds is hence strongly dependent on the vertical distribution of fish schools and their behaviour.

## 1.2 Zooplankton

Zooplankton composition has proven to be a clear environmental indicator, e.g. in changing nutrient levels in the Wadden Sea (Fransz et al., 1992). Even though zooplankton is likely a key factor determining the quality of estuarine areas for juvenile fish, zooplankton studies in coastal or estuarine areas are rare. As a result zooplankton has been ignored in ecosystem wide studies (e.g. Philippart et al. 2007). Changes in regional sea temperatures and the zooplankton composition has shown to be correlated to and affect plankton eating fish (Beaugrand et al. 2003).
At present there is no zooplankton monitoring programme in the Dutch Wadden Sea in the Netherlands. In order to fill this gap we tested a cost-effective sampling method using the Continuous Plankton Recorder (CPR) approach of the Sir Alister Hardy Foundation for Ocean Science (SAHFOS).

Zooplankton is characterised by strong seasonal variations in abundance and species composition and requires high-frequency sampling. The advantage of the CPR approach is that it is less laborious and time consuming, when compared to net sampling and allows recordings at a high frequency. As there is no experience in applying the CPR methodology in shallow coastal waters such as the Wadden Sea, the current study is considered to be a pilot study. If successful, it would offer a new methodology for continuous recordings of zooplankton that can be applied in numerous habitats difficult to access with commonly used sampling techniques. In this report the installation of the plankton recorder, the collection and analysis of zooplankton samples are described.

## 1.3 Hydro-acoustics

Hydro-acoustic surveys are an efficient tool in describing spatial distribution and biomass estimates of pelagic fish over large areas. An area is covered by a vessel by means of transects. The vessel uses an echosounder: which a device which transmits sound pulses and receives their echo's. The time interval between the emission and return is a measure for depth. In the same way, schools of fish can be detected: the strength of the echo is a measure for the density of the school or the quantity of fish. However, additional trawl hauls are required to validate the acoustic observations on fish density and distribution. In addition, catching fish enables collecting biological data (length, age, sex and maturity). When an undefined school of fish is detected by means of echolocation, a haul is made to investigate species composition and length distribution. The net is shot within 15 to 20 minutes after detection of the school. Hauls for species identification can therefore never be planned in advance and are not randomly spread (Figure 1).

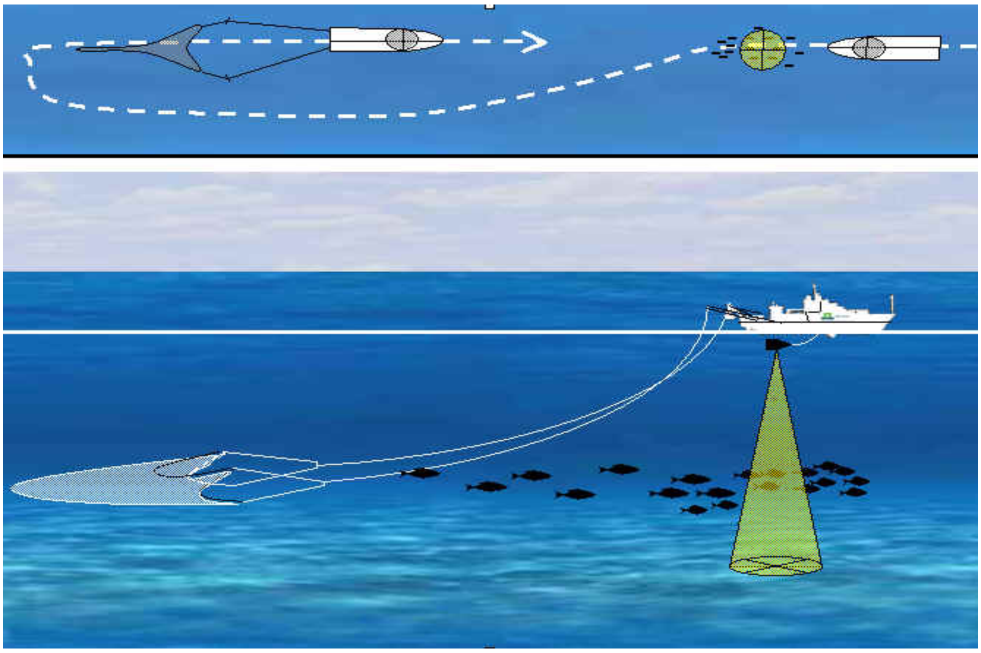

*Figure 1.* *Scheme of the sampling method for pelagic fish. When an undefined school of fish is detected on he echo-sounder (B), the vessel turns and shoots a pelagic trawl within 15 to 20 minutes.*

In order to explore the possibilities for a cost effective standardised method to monitor pelagic fish, an echosounder was installed on the TESO ferry, which operates between Den Helder and the Texel to test the feasibility of on-going routine monitoring. Additionally four hydro acoustic surveys were carried out in the Marsdiep – the water channel between Den Helder and Texel - tidal basin, in spring and autumn 2009 and 2010. In order to test the possibility to monitor plankton, an Autonomous Plankton Recorder (APS)was installed on the ferry between Harlingen and Vlieland. The APS collects (zoo)plankton from water that is pumped up from the water column during cruising. Several transects can be stored automatically in a box with a fixative, allowing operation on commercial vessels.

## 1.4 Objectives

The objectives of the research described in this report are to conduct a number of tests runs of two monitoring techniques new to the Wadden Sea area:

1. echosounders to detect pelagic fish schools and
2. an Autonomous Plankton Sampler (APS) to detect plankton

These tests are conducted within the context of setting up cost effective standardised methods for monitoring pelagic fish and zooplankton for the next years/decades in the Wadden Sea area. The aims of the monitoring program are to:

- Monitor the trends in biomass, size structure, species composition and biological parameters of pelagic fish
- Monitor the trends in abundance and species composition of the zooplankton (APS)
- Develop a cost-effective acoustic monitoring programme for pelagic fish

This report describes the installation of the acoustic (chapter 2.1) – and plankton recording equipment (chapter 2.2) and the results of the tests carried out with these devices (chapter 3.1 and 3.2, respectively).

The objective within the test runs are

- to calculate the biomass is of pelagic fish in the Marsdiep area by means of echo integration (Simmonds and Maclennon, 2005)
- to describe approximate dimensions of schools as well as their vertical and horizontal movements in relation of the tide
- to describe catch composition and length frequency distribution
- to evaluate the use of an echosounder on board the TESO ferry

# 2 Materials and Methods

Figure 2 presents the survey area. An overview of the days of data collection, hauls and samples collected in this project for the acoustic – and the plankton sampling part can be found in **Fout! Verwijzingsbron niet gevonden.**. An overview of platforms used during this study is provided in Figure 3.


*Figure 2 The Marsdiep area between Den Helder and Texel. The polygone gives the boundary of the area for abundance estimation.*

*Table 1 Overview of surveyed days during this study. Survey days during the acoustic surveys include the time spent for the calibration of the equipment and the steaming up to the Marsdiep area from IJmuiden*

| | Acoustic | | Zooplankton sampling | |
|---|---|---|---|---|
| Date (start) | trial TESO (days) | survey (hauls) | ship/ platform | samples/ analyses |
| April 2009 | | | NIOZ quay | Initial testing |
| April 2009 | | | MS Vlieland | Plankton sampling (analysed) |
| 17 May 2010 | | 5/19 | | |
| 14 September 2010 | 2 | | | |
| August 2010 | | | Zilvervisje | Plankton sampling (no analyses) |
| November 2010 | | | FRV Tridens | Plankton sampling (no analyses) |
| 11 October 2010 | | 5/19 | | |
| 26 October 2010 | 5 | | | |
| 2 May 2011 | | 5/18 | GO58 | Plankton sampling (analysed) |
| 4 May 2011 | 1 | | | |
| 17 October 2011 | | 5/9 | | |


*Figure 3. Platforms used during this study - Upper left: aluminium flat bottomed research vessel "Zilvervisje". Middle left: chartered fishing vessel GO58, which was used for the acoustic surveys in*

*May and October 2010 and 2011. Middle right Ferry MS Vlieland. Below: Fisheries Research Vessel Tridens.*

## 2.1 Hydro acoustics

### 2.1.1 Installation of an echosounder on board the TESO Ferry

The 200 kHz transducer and transceiver was installed in the moon pool of the TESO ferry in September 2010. Technically the equipment worked fine. The depth of the transducer in the moon pool was at 5 m below the water surface: any fish swimming higher in the water column would be missed.
During the third quarter of 2010 two days data were collected. The echograms showed a lot of transmission loss, probably due to air bubbles.

### 2.1.2 Surveys

Four hydro acoustic surveys were carried out: 17 – 21 May 2010, 11 – 15 October 2010, 2 – 5 May 2011 and 17 – 21 October 2011 (see Table 1). The acoustic equipment used, was a 38 kHz SIMRAD EK60 splitbeam echosounder, mounted on a towed body (Figure 4). The towed body was towed at approximately 2m depth alongside a chartered fish cutter, the GO58, "Jakoriwi". The Marsdiep area was randomly surveyed between the sand bank "De Razende Bol" at the North Sea side and the Wadden Sea side up to depth of 5m.
In total 132, 164, 160 and 61 – total 517 - nautical miles (nm) were covered in the respective years during the surveys.
In October 2010 and May 2011 in the Marsdiep area, data were recorded on board the TESO ferry; in October 2010 one week later than the survey; in May 2011 on one day during the survey.
Prior to each survey the equipment was calibrated using standard methodology described by the manufacturer (http://www.simrad.com) and can be found in Foote et al. (1982). Calibrations of the two surveys in 2010 took place in the entrance of the port of Rotterdam (Figure 5). For the surveys in 2011, we relied on the calibrations carried out during surveys in the offshore windfarm off Egmond, in April and October, 2011 respectively (calibration reports: Annex I).

Data were analysed with Myriad Echoview software. Within this application an algorithm was applied to distinguish between swimbladdered and non-swimbladdered fish species (see paragraph 2.1.3), where catch data is used to groundtruth acoustic findings. The acoustic target strength (TS) of fishes with swimbladder - in the Marsdiep dominated by clupeids - is several orders of magnitude larger than the TS of non-swimbladdered fishes, in the Marsdiep area consisting mainly of sandeel (*Ammodytes tobianus*) (Simmonds and Maclennan, 2005), for low frequency echosounders such as the 38 kHz used during this study. As a result a mix of acoustic indications of the latter with echo's from swimbladdered fishes would create a large overestimation if echo's from clupeids are wrongly assigned to sandeel. On the other hand is echo's from sandeel are wrongly assigned to clupeids this will have an negligible effect on the abundance estimation. Therefore echo integration was only applied to clupeids.

*Figure 4* *Towed body, hoisted on board.*

*Figure 5* *Calibration of the EK60 echosounder was carried out in the entrance of the port of Rotterdam.*

### 2.1.3 Analysis

#### *2.1.3.1 Identification of clupeids and school dimensions*

The acoustic data were analysed with post processing software *Myriax Echoview* (http://www.echoview.com). Echoview uses algorithms to create so called synthetic echogram, transformed echograms or filtered echograms. The algorithm used in the present study was designed to exclude everything but clupeid schools. The algorithm cleaned the data from background noise and excluded data below 0.5 m of the bottom or above 0.5 m below the surface. The data were blurred and a median filter was applied to make schools more visible, before the school detection algorithm, included in *Myriax Echoview*, was run. The mean TS of each school was computed and a threshold of -45 dB was applied as this is the frequency that has shown to distinguish Clupeid schools in the uppers 50m of the water column in fisheries hydro acoustics (i.e. Fassler et al, 2011) . Thus each school with a strong mean TS was kept as a clupeid school. Results were exported based on the selected schools, masked with the raw data. Export in Echoview was carried out by region and by cell, so that values for each school with depth information were generated. The resulting files contained information about the position of the data points (GPS information, latitude, longitude and time), the depth of the detected schools, the *Nautical Area Scattering Coefficient* (NASC, e.g. the reflected surface of acoustic energy in $m^2/nmi^2$), school height and length (m), maximum circumference (m) and area of the slice at the circumference ($m^2$), school surface ($m^2$) and volume ($m^3$) (Figure 6).

After applying the Echoview algorithm, additional filtering of the dataset was carried out by removing extreme values. This was necessary because the threshold for school detection was set very broadly (not restrictive), to be able to include a large range of school sizes and shapes, especially very small schools. This resulted in detections of schools of extreme size, which were removed after expert judgement. The following records were removed : school length < 550m; school height(m) < length/1000, height < 0.01m; slice-area < $0.01m^2$, circumference < $0.01m^2$, slice-area/circumference1 < 0.01, length < 0.3m, school volume < $0.001m^3$, NASC > $2.10^5$ $m^2/nmi^2$.

#### *2.1.3.2 Vertical fish distribution in relation to tide*

The resulting vertical distribution was tested against the predicted tide. Tidal information – water level per ten minutes - was taken from http://live.getij.nl/getij_locaties.cfm?taal=nl for the location of Den Helder. The water level was compared to the presence of fish (NASC) per 1 m vertical layers and 20 minute intervals.

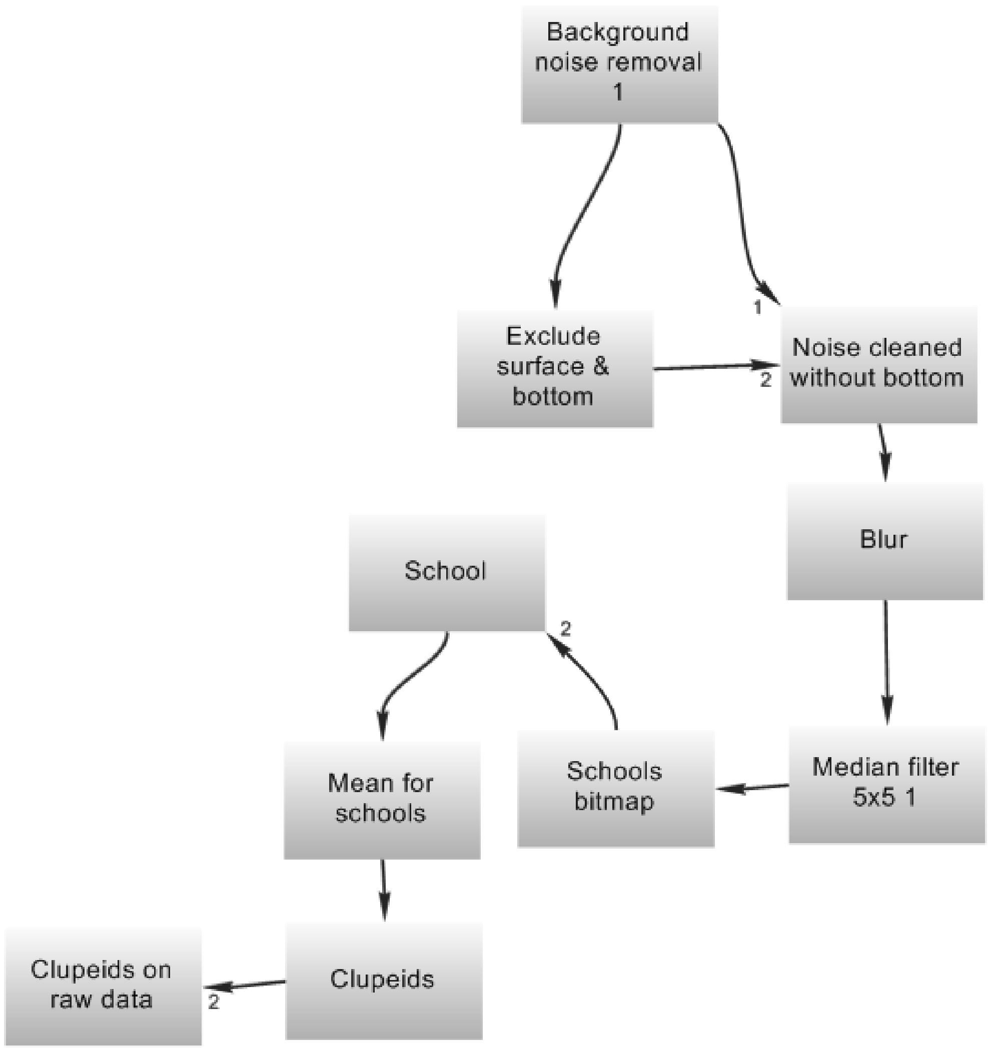


*Figure 6 Schematic presentation of the algoritm applied to detect clupeid school with the post processing software Myriax Echoview (Figure taken from Myriax Echoview manual).*

### *2.1.3.3 Fish catches*

The acoustic recordings were verified by fishing with a semi pelagic trawl "Zwever" with a 6 mm meshes codend lining, an effective trawl opening of approximately 12 meter horizontal and 5m vertical (Annex II). The fishing speed was 3.3 knots through the water. Fishing was carried out to identify species-composition of recordings observed on the echo sounder and to obtain length frequency samples of herring and sprat. In general, after we decided to make a tow with a pelagic trawl (based on the echo information), the vessel turned and fished back on its track line. All hauls were executed in midwater, mostly close to the surface.
The catch was subsampled and divided in species fractions. The weight of the subsample was estimated or measured with a scale (=/- 10 g), length estimates were obtained through measuring up to 150 specimens rounded down to the nearest cm, i.e.: 10.7 cm is recorded as size class 10 cm.

### *2.1.3.4 Abundance estimation*

For an arbitrary polygon area (Annex III), established for each survey, length distribution of clupeids and sandeel were determined as the un-weighted mean of all trawl results. Within the polygon, the number of surveyed nautical miles were 97, 116, 68 and 28 nm for each survey respectively. From these

distributions the mean acoustic backscattering cross-section "sigma" ($\sigma_{bs}$) was calculated according to the target strength-length relationships (TS) recommended by the ICES Working Group on International Pelagic Surveys (PGIPS; http://www.ices.dk/community/groups/Pages/default.aspx#k=wgips ): TS=log (length) –71.2. The numbers of herring and sprat were calculated by dividing the NASC by the overall $\sigma_{bs}$ in the Marsdiep area. The mean weight of all clupeids (Herring, Sprat, Pilchard, Anchovy) in the catches was calculated by applying the standard length weight relationship ($W=aL^b$) found by Grift et al (2004) for sprat off the Dutch coast: a=0.004 and b=0.23 during the second quarter; a=0.0058 and b=2.85 during the fourth quarter.
The abundance of sandeel was calculated based on the number of fish caught per area fished in the trawl hauls, assuming that fish did not escape the net. The distance fished was calculated by multiplying the trawl speed with the trawl time. The area fished was calculated by multiplying the distance with the effective horizontal opening of the net. The total area within the polygon was divided by the area fished. Multiplication of this quotient with the actual weight caught, gives the total fish abundance.

## 2.2 Zooplankton

Five cruises were carried out to test the set-up of a zooplankton sampling system by means of an on-board Autonomous Plankton Sampler (APS) based on the Continuous Plankton Recorder system (Figure 4, Table 1). Based on its performance, the set-up of the sampling system was changed from one cruise to another, to improve the sampling of zooplankton. Carrying out standardised sampling was not the purpose of this study at this stage.

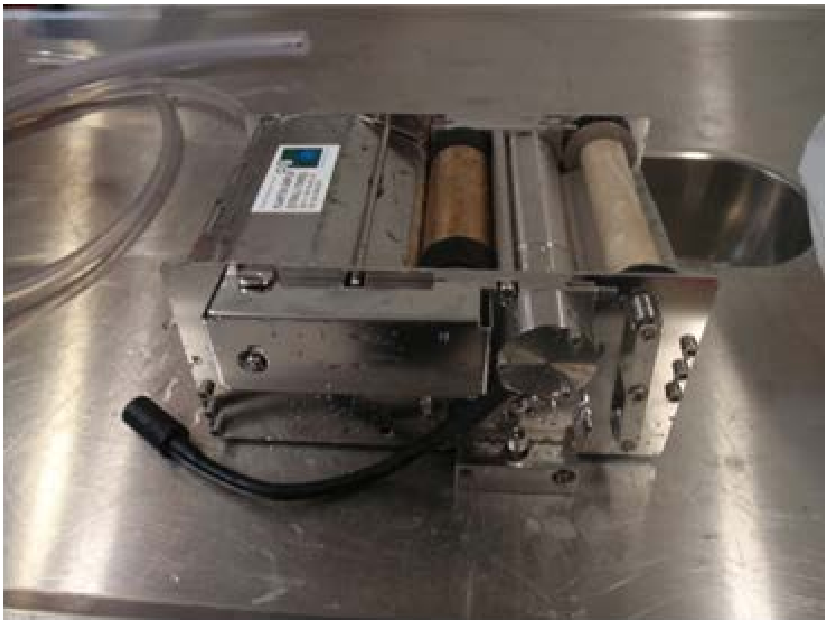

*Figure 7 The plankton sampling unit ("plankton recorder") of the APS.*

### 2.2.1 Description of the APS and sample treatment

A CPR system (Continuous Plankton Recorder) was adapted in cooperation with Chelsea Technologies (CTG) in order to enable the on-board application of sampling. The CPR system is towed behind a ship, sampling the water *in situ*. With the Autonomous Plankton Sampler (APS), water is pumped from the sea through a programmable and thus autonomous plankton recorder. Zooplankton is captured between two

layers of gauze inside the plankton recorder and subsequently wrapped on a gauze roll soaked in preservation fluid. Samples were taken during sailing.
This system has the advantage that no gear is set overboard, thus excluding the risk of mechanical damage to the recorder, the ship or other obstacles. In addition, maintenance can be reduced to a minimum, because the APS can be programmed for a sequence of sampling events in advance, and all parts are readily accessible from inside the ship. Digital data logging and a computer interface in principle allow coupling of the flow data with concurrent measurements of temperature/salinity and GPS position.
After initial testing it appeared that technical adjustments to the sampling system were necessary, involving changes to the intake of water. Unfortunately, it was not allowed by the ship owner to make changes to the inflow system in the hull of the ship. Therefore, the APS system was tested at different platforms of opportunity (e.g. research vessels).

*Sampling and sample treatment*
Zooplankton was collected on gauze with a mesh size of 150 µm (as provided with the CPR) for the duration of 10 to 25 minutes per sample, representing a water volume ranging from 0.5 to 1.5 $m^3$. After one sampling phase, the gauze was rolled into preservation fluid (borax buffered formaldehyde-seawater solution). During sailing, multiple samples were collected (Figure 8), and the gauze was recovered in the laboratory. Sections of the gauze representing one sample were cut and stored in a small bottle on buffered formaldehyde-seawater solution (3.7%). The gauze was rinsed with seawater to extract the plankton from the net. The net was further inspected to assure that all zooplankton was removed. A sample was rinsed into a Bogorov plankton counting chamber, and plankton was identified on the level of higher taxonomic groups (order, family and genera).

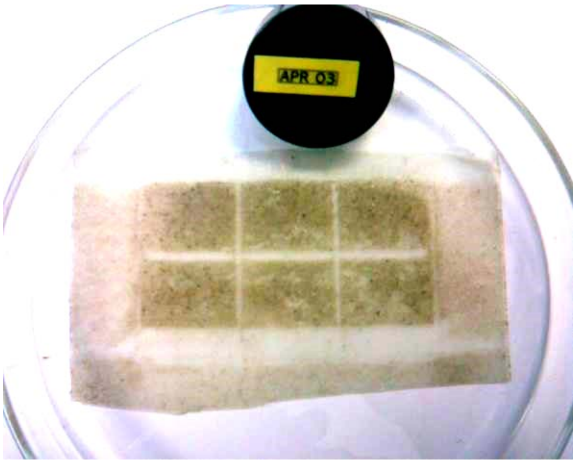


*Figure 8 A typical sample of the APS after 20 minutes of sampling.*

### 2.2.2 Applications of the APS

A first trial was carried out on board of the Ferry “MS Vlieland” sailing from the city of Harlingen at the main land to the isle of Terschelling in the Wadden Sea. The MS Vlieland’s compartment where the ship’s seawater system intake is situated was found suitable for the installation of the APS. A separate access to seawater could be used to provide the APS with seawater from outside the ship’s hull using 1” piping (see also Annex VI). The seawater inflow was approximately 1.5 m below the waterline, with an opening of 12 $cm^2$ (outer diameter approx. 2.5 cm) directed perpendicular to the ship hull (see Annex VI). A self-priming centrifugal pump was installed downstream of the APS to establish a constant flow of water through the APS during sampling. The piping system that connects the sea water inflow with the APS and the pump was installed during the MS Vlieland's docking period in March 2009. The APS itself and the pump were installed shortly after delivery on June 3rd, 2009. Samples were taken during sailing with a speed of about 12 knots.

Since the preliminary installation of the APS on MS Vlieland in 2009 had yielded too low numbers of zooplankton, the aim in 2010 was to investigate possible improvements of the sampling efficiency of the Autonomous Plankton Sampler (APS). The poor performance could have been due to the small opening and direction of the collecting pipe and/or the high speed of the vessel. In August 2010, a mobile system was developed to test sampling with a larger opening by means of a gauze funnel (10x20 cm) directed in the sailing direction, and at lower sailing speed. A mobile APS system was installed on board of the small vessel Zilvervisje (Figure 9). Samples were taken in the Wadden Sea close to isle of Texel in August 2010. Zooplankton samples were collected and analysed to assess the performance of the sampling set-up. The results of this test indicated that the adapted mobile APS system using a gauze funnel at the inflow opening yielded zooplankton abundances in an order of magnitude realistic for the Wadden Sea (see results section).

*Figure 9 Testing of mobile APS on board of the small research vessel Zilvervisje.*

After further improvement of the system, the mobile system was tested again during an zooplankton survey on board of RV Tridens in November 2010. The gauze funnel was installed aside the ship at about 1.5 m depth (Figure 10) in order to test a more robust system (funnel) at higher sailing speed. Different funnel sizes were tested; 10x10 cm, and 10x20 cm openings, with the opening directed in the sailing direction, and at various angles for comparison. The system operated well during offshore conditions and zooplankton samples were collected at sailing speeds of up to 13 kn. However, no priority was given to analyse the samples for species and counts, since they were taken outside of the Wadden Sea. The main result was the demonstration of the robustness of the system.

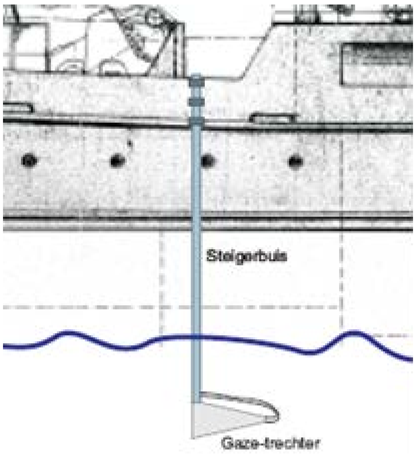


*Figure 10 Drawing of inflow pipe on the RV Tridens.*

In 2-4 May 2011, the system as applied on the RV Tridens was implemented on board of a commercial fishing vessel (GO58). A survey was carried out in a concerted action with the acoustic work, with the aim to collect relevant data for the Wadden Sea. Zooplankton samples were taken and analysed.

A summary of surveys is presented in Table 2.

*Table 2 Summary table of zooplankton surveys to test the on-board APS system*

| **Code** | **Sampling vessel** | **Sampling location** | **Sampling date** | **Description of set-up and adaptations** |
|---|---|---|---|---|
| V 2009* | Ferry Vlieland | Harlingen-Vlieland transect | April 2009 | Water pumped from sea water system of Ferry; opening 2cm$^2$, direction at right angle of ship hull |
| V2009a | Ferry Vlieland | Harlingen-Vlieland transect | June 2009 | No changes |
| V2009b | Ferry Vlieland | Harlingen-Vlieland transect | July 2009 | No changes |
| M 2010 | Zilvervisje | Wadden Sea near Texel | August 2010 | Water pumped through gauze funnel opening (200 cm$^2$), directed in sailing direction of ship (similar to Figure 10) |
| N 2010 | RV Tridens | North Sea | November 2010 | More robust gauze funnel systems (100 and 200 cm$^2$), offshore conditions, high sailing speed |
| W 2011 | GO58 fishing ship | Wadden Sea | May 2011 | Gauze funnel system 200 cm$^2$, Wadden Sea sampling |

Selected samples were analysed from the monitoring of zooplankton, since the focus was on the technical implementation of the Autonomous Plankton Sampler (APS). Samples from the trial runs were analysed for surveys in 2009 taken on board of a Ferry, for 2010 from a small research vessel and in 2011 taken from a commercial ship. The efficiency of the catch is reflected by the composition of taxonomic groups in the samples, and the density of zooplankton, calculated form the numbers caught and the volume of water sampled by the APS.

# 3 Results

## 3.1 Hydro acoustics

### 3.1.1 Recordings from the TESO ferry

The quality of the data from the echosounder installed in the TESO ferry were too poor to base an accurate species identification and biomass estimation on, as illustrated in Figure 11.

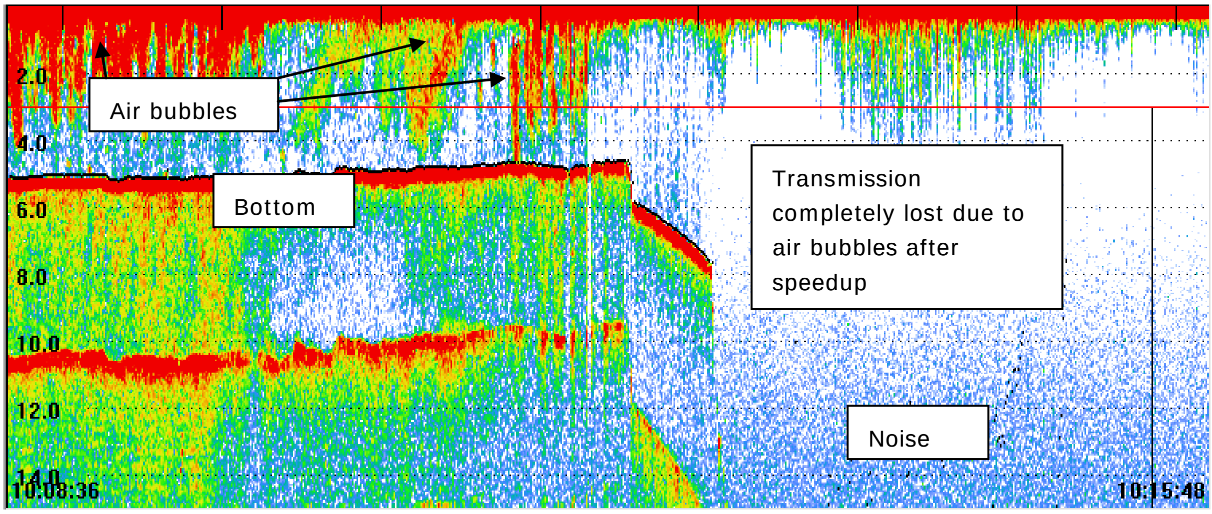


*Figure 11 Echogram (200 kHz) from 26 October in the Marsdiep from the echosounder mounted in the TESO line. After the ferry leaves the dock, blobs of air bubbles are visible. After speedup, the echosounder suffers from transmission loss, indicated by the disappearance of the bottom and the noise in the water column. (the red line is a boundary line for echo integration in the interface of the echosounder).*

### 3.1.2 Hydro acoustic surveys

The hauls carried out during the acoustic surveys in May and October, 2010-2011 and the polygon for the calculation of the abundance of pelagic fish are presented in Figure 12. Annex IV provides the survey tracks across the area for each survey.

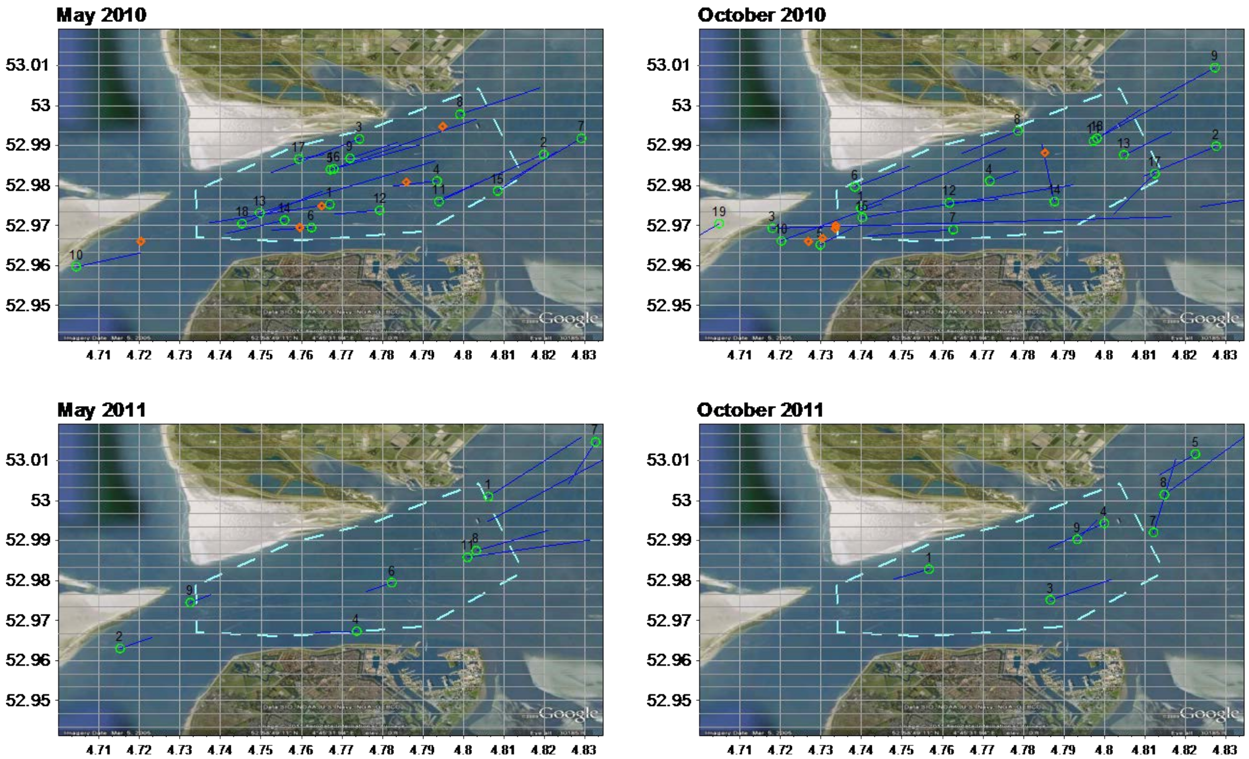


*Figure 12* *Pelagic hauls carried out during the acoustic surveys in May and October, 2010-2011. The starting positions are presented as green circles, the fished track is represented by blue lines. The orange dots in the May surveys are CTD downcasts (not in this report).*

Figure 13 gives an example of a typical 38 kHz echogram in the Marsdiep area.

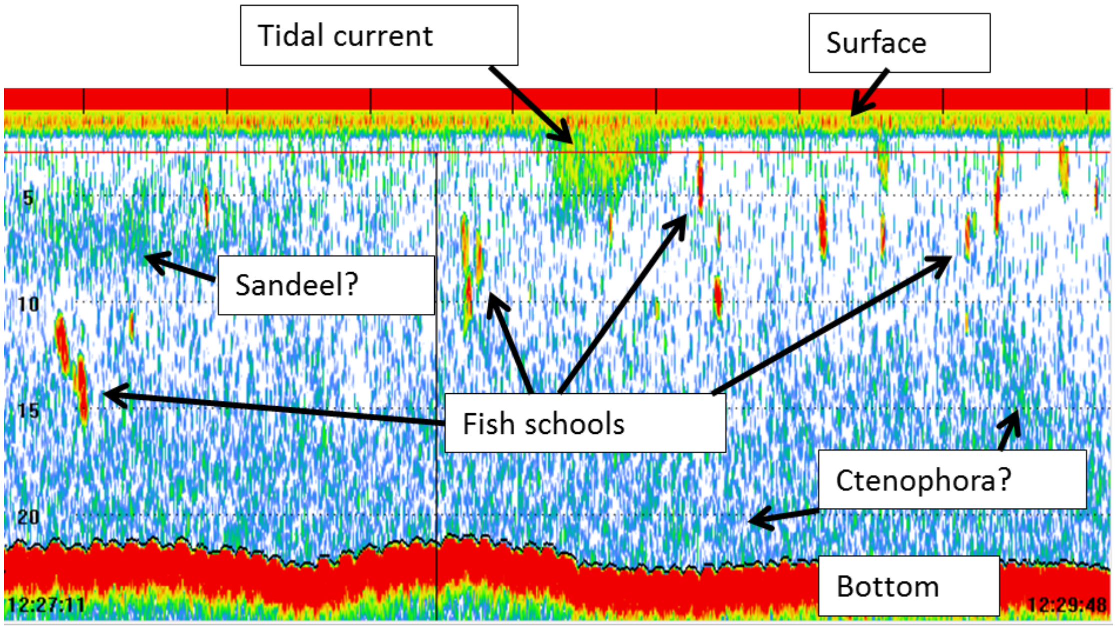


*Figure 13* *Typical 38 kHz echogram in the Marsdiep area. Tidal current and the wake of vessels (not in this echogram) as well as swimbladdered fish congregations can be recognized easily. The recognition of nonswimbladdered fish, plankton and Ctenophora(Comb jellies) is equivocal.*

### 3.1.2.1 Biomass in the Marsdiep area

Table 3 provides the abundance and biomass of clupeids in the Marsdiep area based on acoustic estimates and biological measurements. The mean length of clupeids (8.2 cm) in May 2010 was large compared to the mean length in October (7.3 cm), whereas the mean length in October 2010 (5.9 cm) was smaller than in October 2011 (7.9 cm). The biomass in the Marsdiep area, based on the mean weight and the NASC is in May higher (612 tonnes in 2010 and 369 tonnes in 2011) than in October, where the estimates are remarkably similar for both years (67 tonnes and 69 tonnes).

The biomass of clupeids in the area is much higher, by a factor of 20 in October, when compared to demersal fish biomass estimates raised to the same water volume in the Demersal Fish Survey (DFS). A rough estimate for sandeel, based on trawled area, is more than 20 tonnes in May and 0 tonnes in October. If the trawl catch rates of clupeids are raised to the area, the biomass is in the range of (low) hundreds of tonnes (Table 4).

*Table 3 Abundance and biomass by survey, based on Nautical Area Scattering Coefficient's (NASC), acoustic Target Strength (TS) calculated from the mean length from all hauls, acoustic cross section (σbs) and the mean fish weight calculated from the length according to the standard length weight relationship ($W=aL^b$) as found for sprat by Grift etal (2004).*

| survey | mean length (cm) | TS (Db) | $\sigma_{bs}$ | NASC | suface nm2 | abundance | mean weight (g) | biomass (kg) |
|---|---|---|---|---|---|---|---|---|
| May 2010 | 8.2 | -52.9237 | 0.000064 | 1551.987 | 7.225 | 174939643 | 3.5038 | 612955.3 |
| October 2010 | 5.9 | -55.783 | 0.000033 | 339.3784 | 7.225 | 73893830.3 | 0.9128 | 67447.27 |
| May 2011 | 7.3 | -53.9335 | 0.000051 | 1077.486 | 7.225 | 153247724 | 2.4097 | 369278.2 |
| October 2011 | 7.9 | -53.2475 | 0.000059 | 269.606 | 7.225 | 32741865.7 | 2.0973 | 68670.25 |

*Table 4 Estimates of biomass and densities in the Marsdiep area. The first column gives the abundance of swimbladdered fish (dominated by Clupeids) calculated by means of echo integration. The third gives the estimates abundance of demersal fish in the DFS to illustrate that pelagic fish outnumbers demersal fish by a factor of 20. The third and fourth column gives the biomass estimate of sandeel, based on trawled surface.*

| (tonnes) | transects surveyed inside/outside polygon - nmi | survey - ZKO Pelagic fish Marsdiep (clupeids) -tonnes(kg/ha) | Demersal Fish Survey (DFS) Western Waddensea -tonnes(kg/ha) | length of trawl track in + outside polygon - nmi | Rough estimate based on fished surface ZKO Marsdiep survey (sandeel) -tonnes(kg/ha) | Rough estimate based on fished surface ZKO Marsdiep survey (clupeids) tonnes(kg/ha) |
|---|---|---|---|---|---|---|
| May 2010 | 97/132 | 613(247.3) | | 14.6 | 21.9(8.9) | 207(83.5) |
| Oct 2010 | 116/164 | 67.4(27.2) | 3.1(1.3) | 15.7 | 0(0) | 277(111.8) |
| May 2011 | 68/160 | 369.3(149) | | 8.1 | 22.2(9) | 504.2(203.5) |
| Oct 2011 | 28/61 | 68.7(27.7) | 2.7(1.1) | 7.4 | 0(0) | 157.6(63.6) |

#### *3.1.2.2 Fish behaviour in relation to tide*

The distribution of fish in the water column is presented in Figure 14. Almost 50% of the fish is found in the upper 6m. Results for fish concentrations in relation to tide (minutes after low tide) are presented in Figure 15 and Figure 16. There is a slight indication of higher fish concentrations in May 2010 during high tide and no indication of any relation to tide in October 2010 and May 2011 (Figure 15). In October 2011 the data collected are too patchy to draw any conclusion.

Figure 16 indicates that in May 2010 the relative fish distribution is higher in the upper layers during high tide, while in October 2011 the relative distribution is higher in lower layers. In May and October 2011 no pattern is visible.

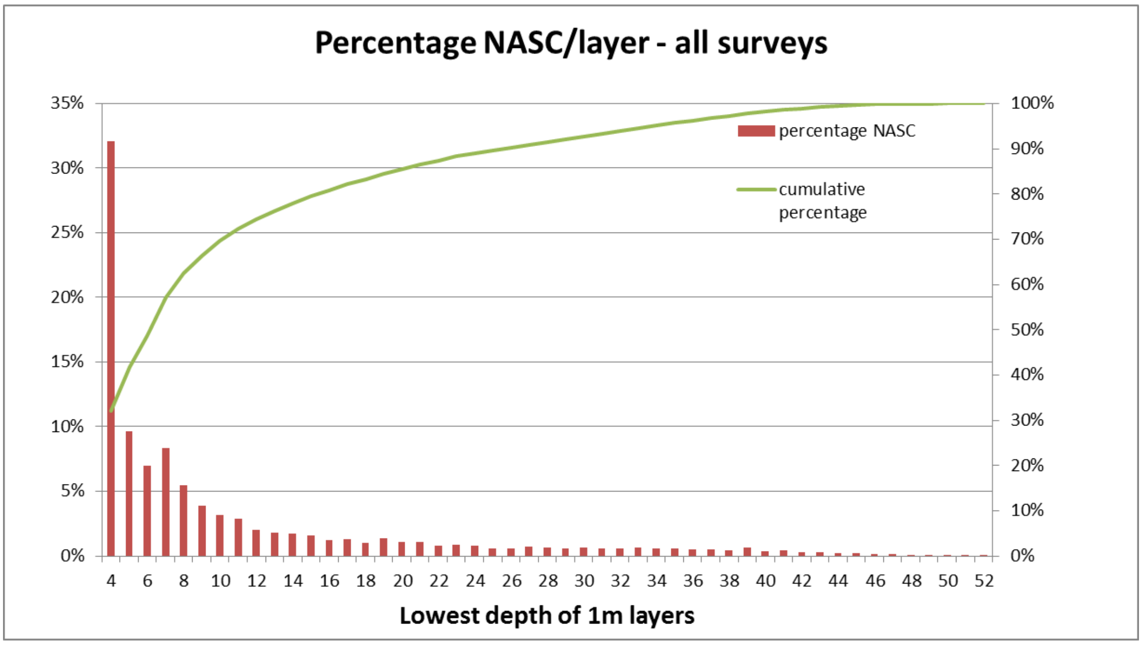


*Figure 14 Distribution of fish in the water column by layers of 1m as percentage NASC (% Nautical Area Scattering Coefficient).*

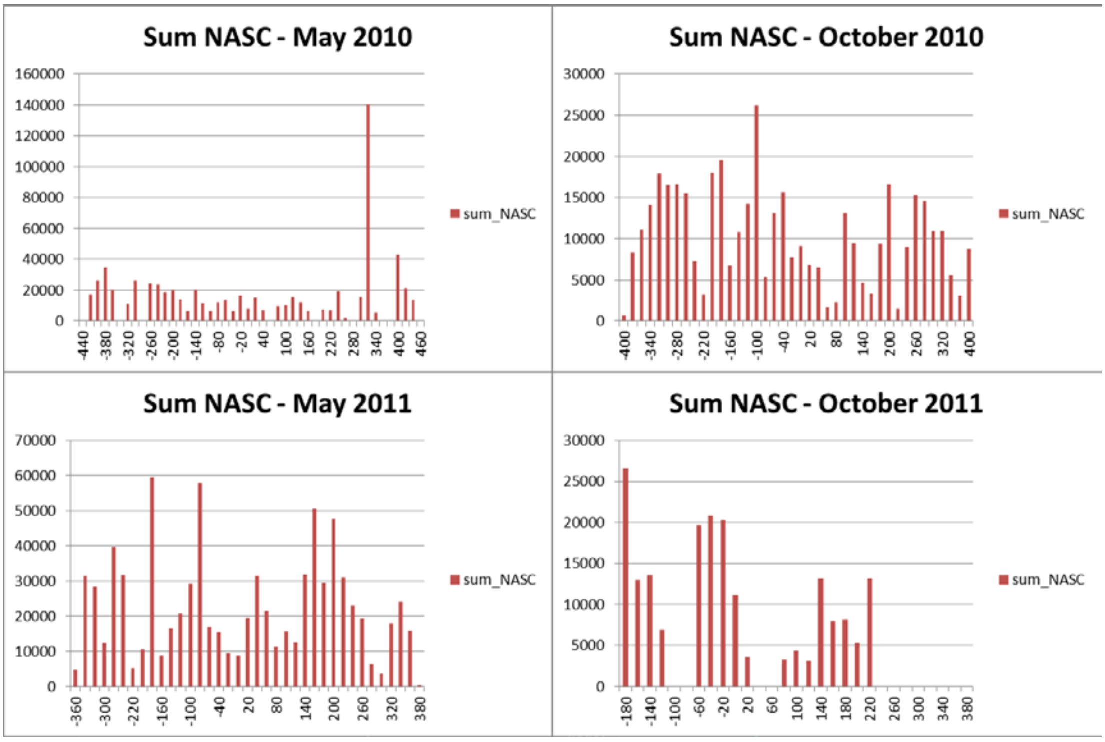


*Figure 15* *Nautical Area Scattering Coefficient (NASC; m2/nm2) in relation to tide. The vertical axis presents the NASC; the horizontal axis presents the tidal state in minutes relative to low tide (0).*

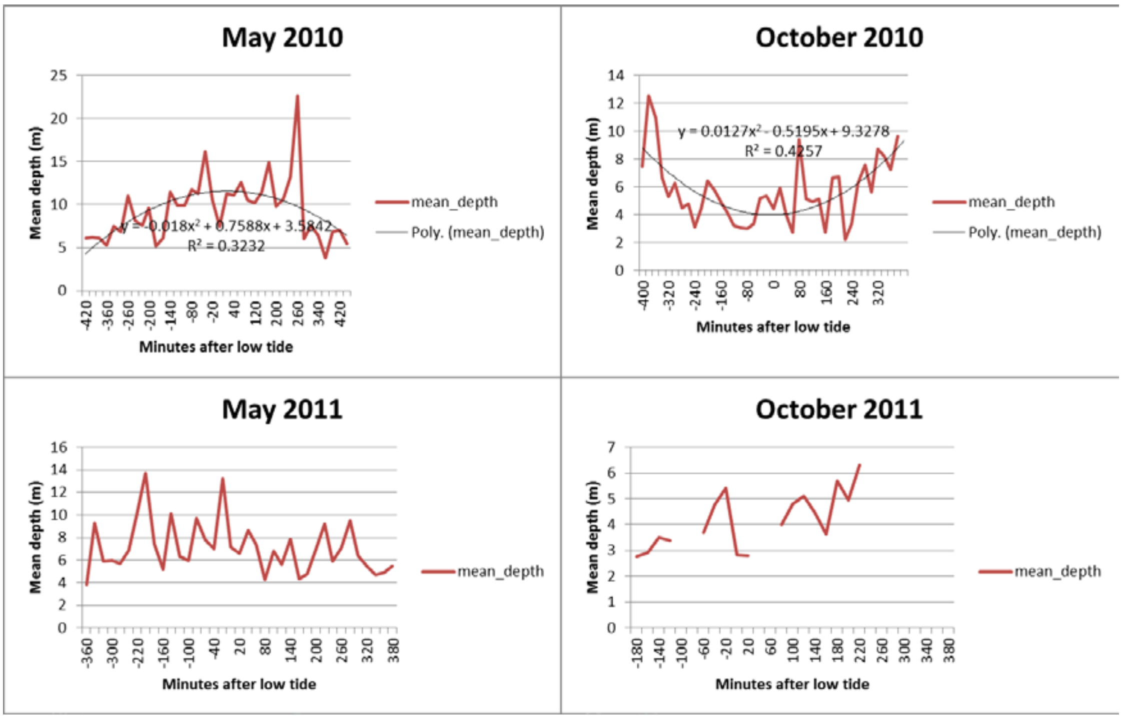


*Figure 16* *Relative fish abundance per depth layer in May and October 2010 and 2011. The vertical axis presents the NASC; the horizontal axis presents the tidal state in minutes relative to low tide (0).*

### 3.1.2.3 School dimensions

School dimensions are presented in Figure 17. In all surveys schools measure typically a few meters in length and in height. In May the schools are larger than in October when most of the schools were smaller than 1m high. Larger schools are less dense than small schools, except very large schools (> 35m long and >8m high).

May 2010

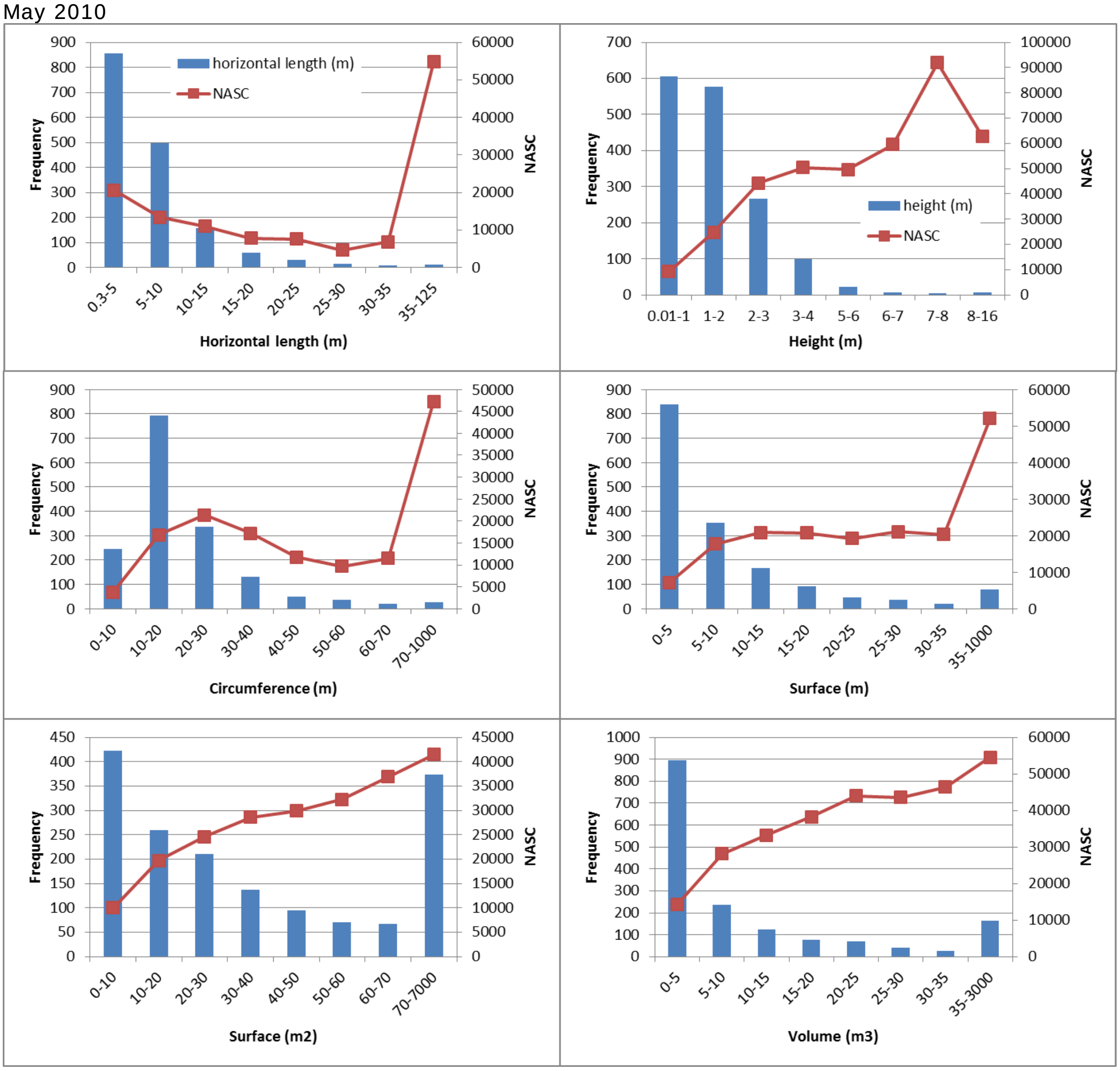


*Figure 17 School dimensions in May 2010. The blue bars and the left axis present the dimensions in terms of length (top graphs), surface (middle) and volume (bottom). The red line (right axis) represents the density of the fish schools as Nautical Area Scattering Coefficient (NASC; $m^2/nm^2$).*

October 2010

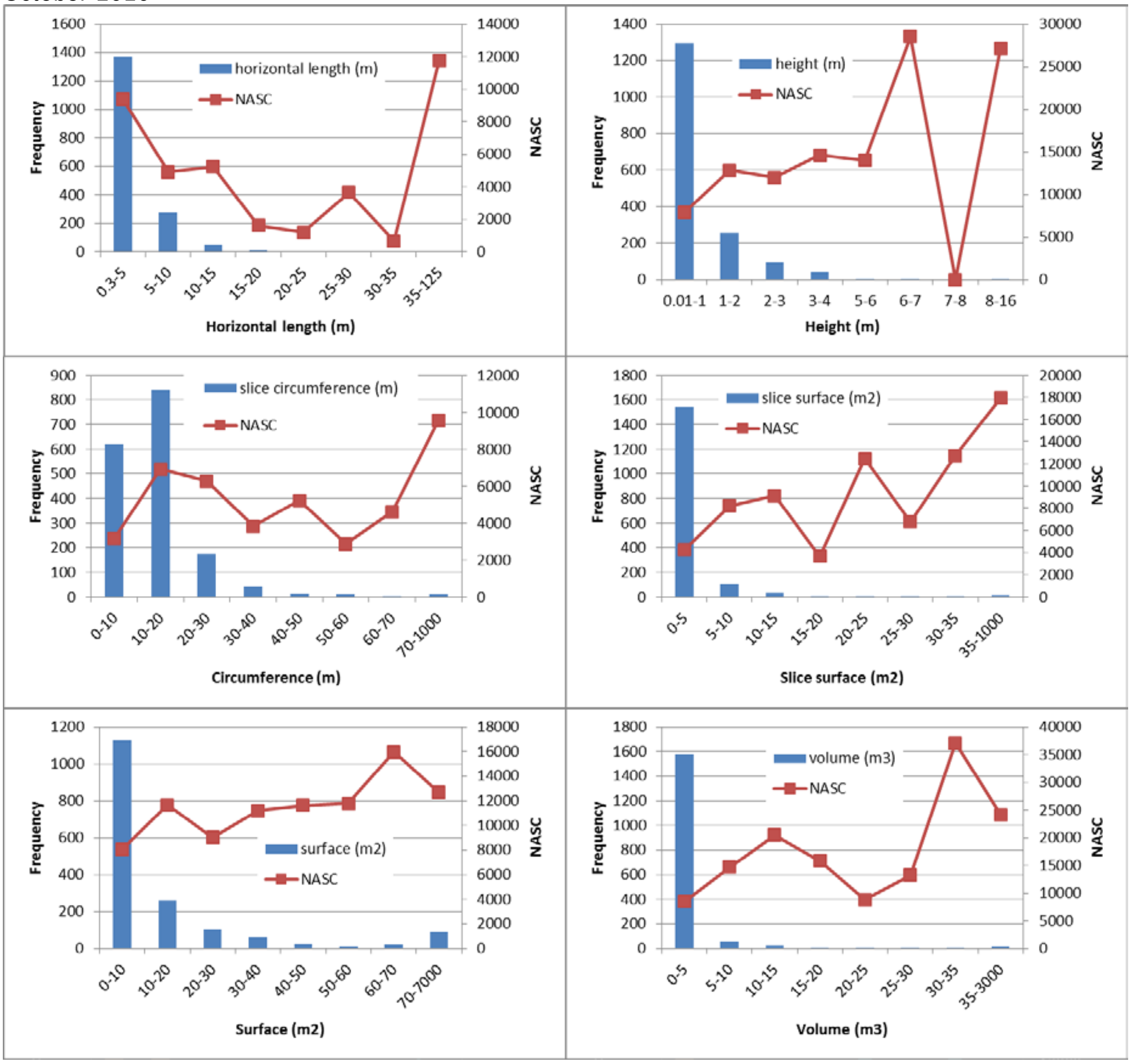


*Figure 17- continued. School dimensions in October 2010. The blue bars and the left axis present the dimensions in terms of length, surface and volume. The red line (right axis) represents the density of the fish schools as Nautical Area Scattering Coefficient (NASC; m2/nm2).*

May 2011

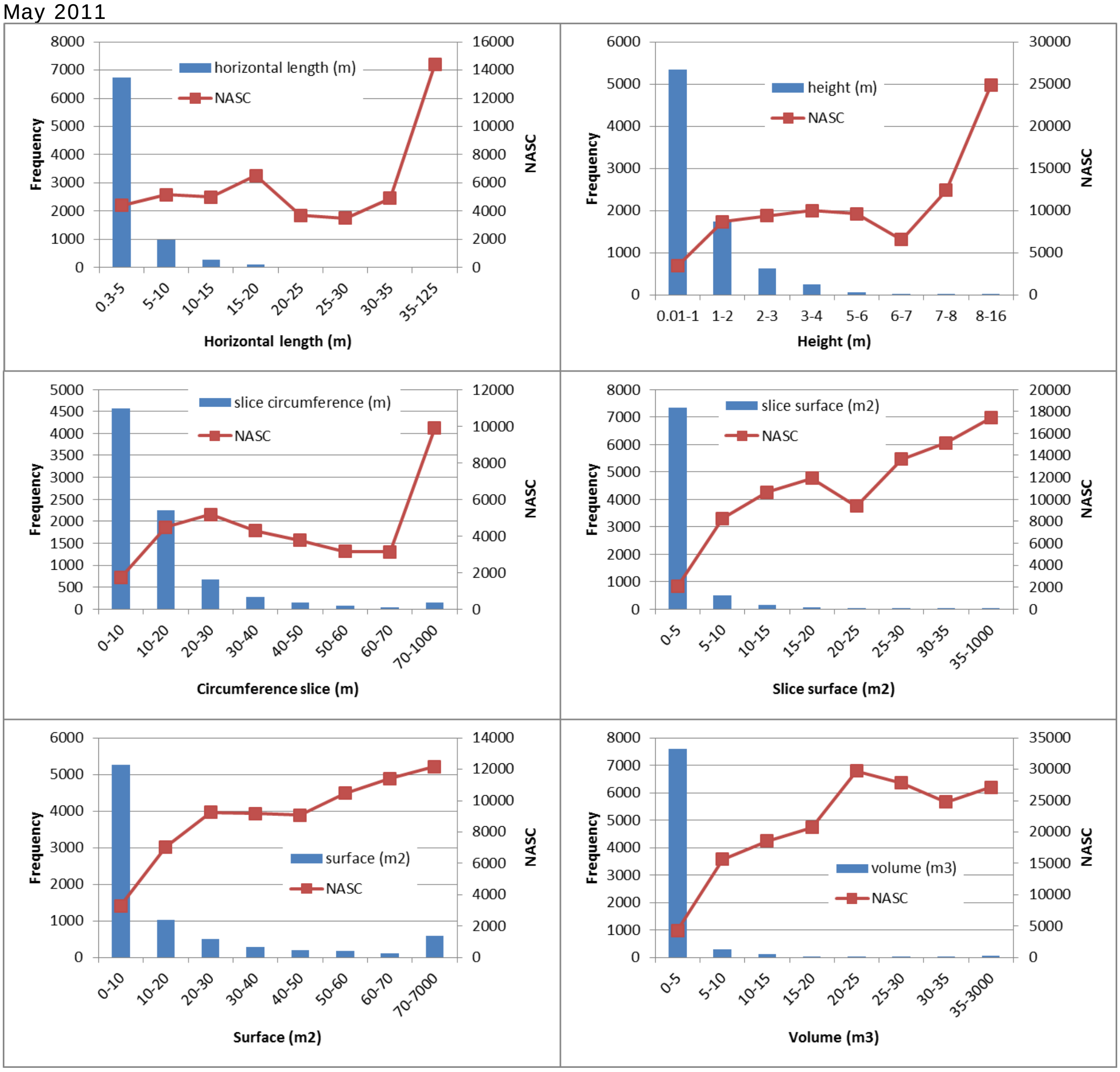


*Figure 17-continued. School dimensions in May 2011. The blue bars and the left axis present the dimensions in terms of length, surface and volume. The red line (right axis) represents the density of the fish schools as Nautical Area Scattering Coefficient (NASC; $m^2/nm^2$).*

October 2011

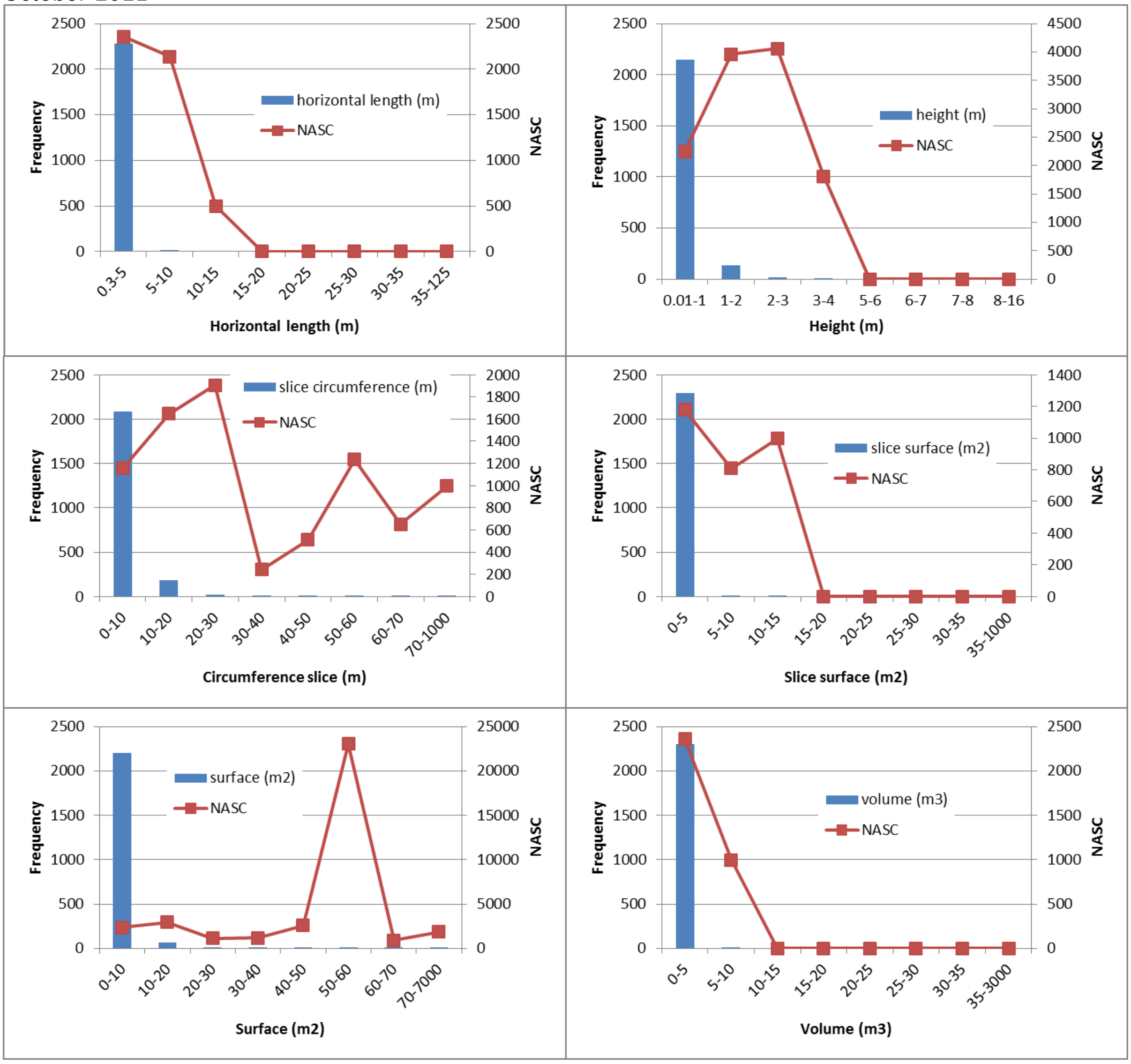


*Figure 17-continued. School dimensions in Oct 2011. The blue bars and the left axis present the dimensions in terms in units of length, surface and volume. The red line (right axis) represents the density of the fish schools as Nautical Area Scattering Coefficient (NASC; $m^2/nm^2$).*

### *3.1.2.4 Catch composition and length frequency distributions*

Table 5 gives a summary of the catch compositions in numbers and weight per hour trawling. See Annex V for a complete list of all species caught. Catches in all four surveys are dominated by sprat: 86.9% of the catches in weight consisted of sprat. In May the second frequent species, was sandeel (9.4% and 7.2% in 2010 and 2011). In October this species was caught only in low numbers or incidentally. In all surveys 5% of the catch consisted of herring. The occurrence of anchovy varied from 5.5% in May 2010 to 0% in October 2011. Pilchard was found in high numbers in the catch in October 2011. In the other surveys this species did not show up in the catches at all. The presence of other species was lower than 1% of weight. Some species were caught only incidentally (Annex Vb).

Figure 18 gives the length distributions of herring, sprat, pilchard, anchovy and sandeel.

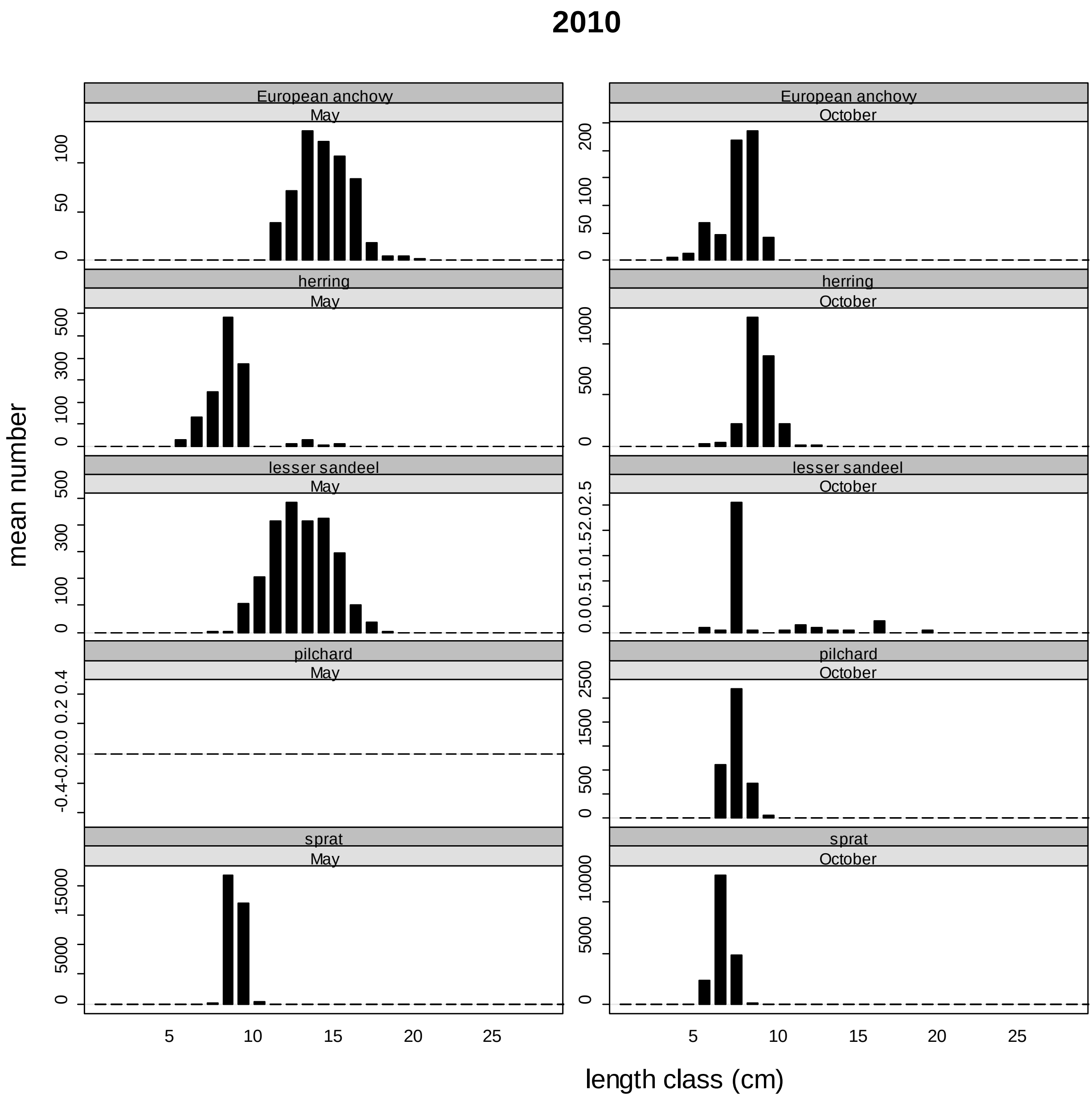


*Figure 18 Length distributions of herring, sprat, anchovy, pilchard and sandeel in the catches of the hydro acoustic survey. In 2011, the catches did not contain pilchard.*

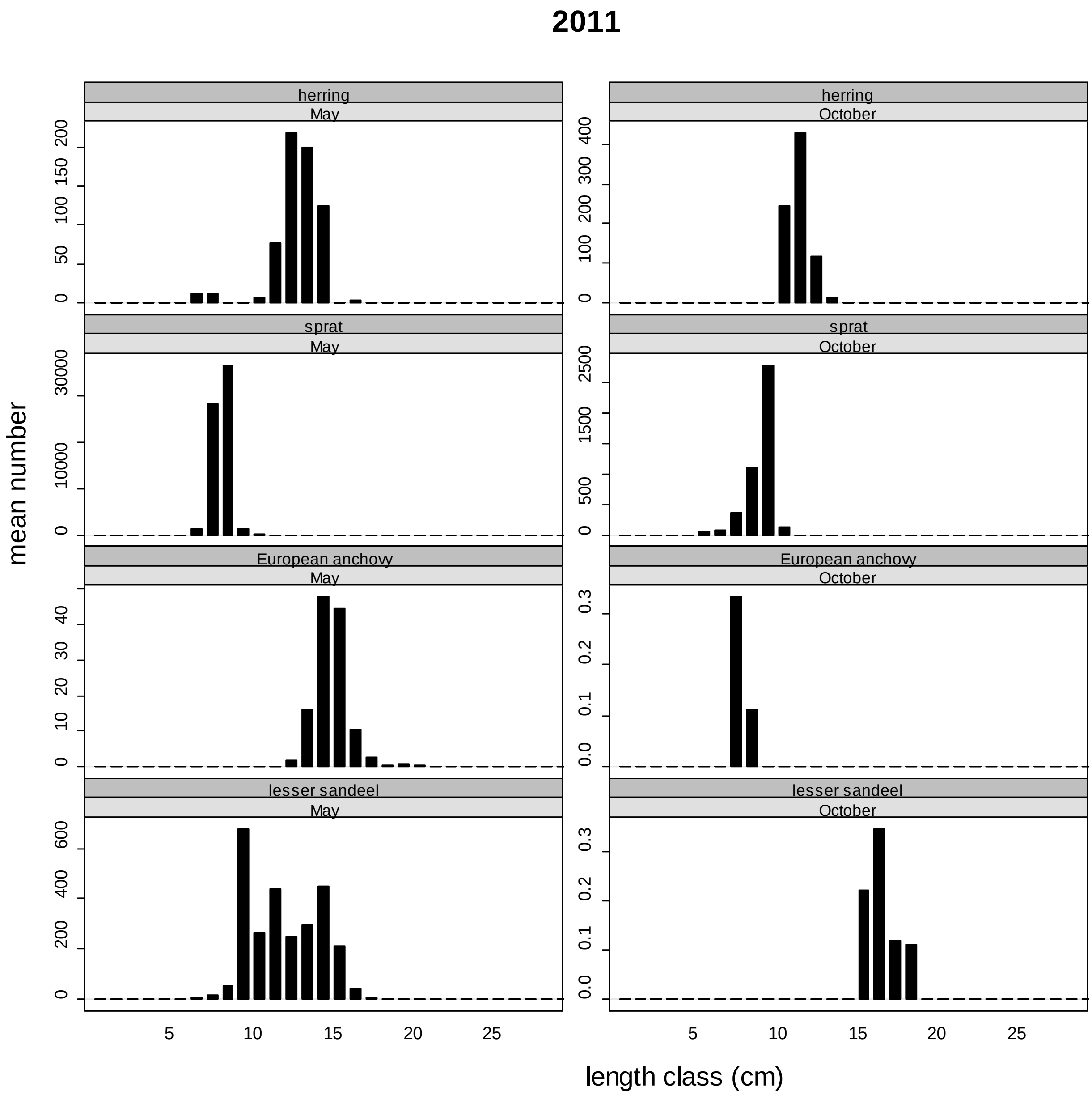


*Figure 18-continued Length distributions of herring, sprat, anchovy, pilchard and sandeel in the catches of the hydro acoustic survey. In 2011, the catches did not contain pilchard.*

*Table 5* *Catch composition of the main species caught in numbers and weight per hour for all surveys. Overall contribution in the catch (% of weight) higher than 3% are in bold.*

| Scientific name | English name | May2010 | | | October2010 | | | May2011 | | | October2011 | | | All surveys | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | number | weight(g) | % of weight | number | weight(g) | % of weight | number | weight(g) | % of weight | number | weight(g) | % of weight | number | weight(g) | % of weight |
| *Ammodytes tobianus* | sandeel | 2459.8 | 16101.9 | **9.4%** | 3.4 | 8.3 | 0.0% | 2701.5 | 13633.4 | **7.2%** | 0.8 | 11.0 | 0.0% | 1291.4 | 7438.6 | **4.3%** |
| *Aphia minuta* | transparent goby | 0.1 | 0.1 | 0.0% | 47.6 | 11.2 | 0.0% | 12.7 | 12.8 | 0.0% | 0.0 | 0.0 | 0.0% | 15.1 | 6.0 | 0.0% |
| *Clupea harengus* | herring | 1430.5 | 5325.6 | **3.1%** | 2697.0 | 12778.2 | **6.0%** | 654.8 | 8073.8 | **4.3%** | 808.7 | 8283.7 | **7.1%** | 1397.7 | 8615.3 | **5.0%** |
| *Cyclopterus lumpus* | lumpsucker | 0.5 | 32.8 | 0.0% | 1.0 | 16.3 | 0.0% | 0.0 | 0.0 | 0.0% | 3.6 | 64.4 | 0.1% | 1.3 | 28.4 | 0.0% |
| *Engraulis encrasicolus* | anchovy | 587.2 | 9298.7 | **5.5%** | 628.5 | 1178.2 | 0.5% | 124.9 | 2178.9 | 1.1% | 0.4 | 0.8 | 0.0% | 335.3 | 3164.1 | 1.8% |
| *Gasterosteus aculeatus* | stickleback | 19.4 | 24.3 | 0.0% | 7.0 | 2.2 | 0.0% | 300.0 | 351.7 | 0.2% | 10.8 | 15.6 | 0.0% | 84.3 | 98.4 | 0.1% |
| *Hyperoplus lanceolatus* | greater sandeel | 5.2 | 129.4 | 0.1% | 5.5 | 66.7 | 0.0% | 10.9 | 327.4 | 0.2% | 4.7 | 58.5 | 0.1% | 6.6 | 145.5 | 0.1% |
| *Osmerus eperlanus* | smelt | 0.0 | 0.0 | 0.0% | 40.4 | 48.6 | 0.0% | 0.5 | 4.3 | 0.0% | 0.2 | 11.4 | 0.0% | 10.3 | 16.1 | 0.0% |
| *Sardina pilchardus* | pilchard | 0.0 | 0.0 | 0.0% | 4587.3 | 9233.4 | **4.3%** | 0.0 | 0.0 | 0.0% | 0.2 | 1.1 | 0.0% | 1146.9 | 2308.6 | 1.3% |
| *Scomber scombrus* | mackerel | 5.1 | 1018.6 | 0.6% | 1.8 | 114.3 | 0.1% | 4.2 | 896.2 | 0.5% | 0.0 | 0.0 | 0.0% | 2.8 | 507.3 | 0.3% |
| *Sprattus sprattus* | sprat | 39269.5 | 137996.0 | **80.9%** | 20125.4 | 191018.2 | **89.0%** | 67655.4 | 163892.2 | **86.3%** | 4495.2 | 108310.7 | **92.7%** | 32886.4 | 150304.3 | **86.9%** |
| *Syngnathus rostellatus* | Nilsson's pipefish | 208.9 | 49.4 | 0.0% | 34.3 | 5.1 | 0.0% | 254.4 | 73.5 | 0.0% | 0.9 | 0.3 | 0.0% | 124.6 | 32.1 | 0.0% |
| *Other species* | | 25.4 | 527.3 | 0.3% | 13.6 | 132.2 | 0.1% | 5.4 | 519.3 | 0.3% | 0.3 | 85.2 | 0.1% | 11.2 | 316.0 | 0.2% |
| *total* | | 44011.5 | 170504.1 | | 28193.0 | 214612.8 | | 71724.7 | 189963.4 | | 5325.9 | 116842.7 | | 37313.8 | 172980.8 | |

## 3.2 Zooplankton

### 3.2.1 Ferry trials

A selection of samples from the Ferry MS Vlieland was analysed for zooplankton (Table 6), and photographs of some samples and organisms are presented in Figure 19 and Figure 20.

*Table 6 Summary of sample inspections*

| Sample | Water filtered ($m^3$)* | Technique | Item | No |
|---|---|---|---|---|
| 20090618-1 | n. a. | Gauze scanning | Cypris larva | 1 |
| 20090618-3 | ~ 0.69 | Rinsing | Cypris larva | < 10 |
| | | | Gastropod | 1 |
| | | | Copepod | 1 |
| 20090716-1 | ~ 0.59 | Rinsing | Mysid | 1 |
| | | | Gammarid | 1 |
| | | | Zoea larva | 2 |
| 20090716-2 | 0.59 | Rinsing | Cypris larva | 2 |
| | | | Zoea larva | 1 |
| | | | Bivalve | 1 |
| | | | Cumacea | 1 |

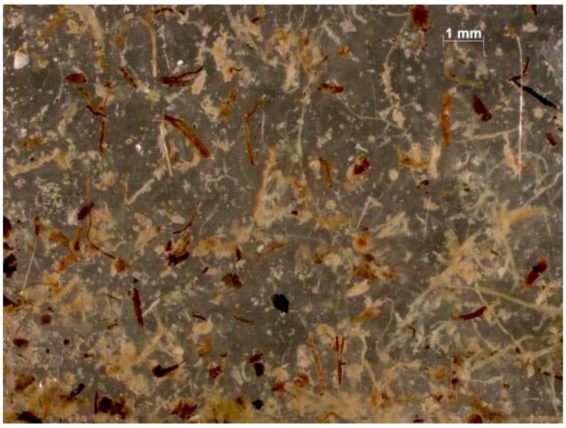


*Figure 19 Close-up of sample 20090618-3*


*Figure 20 Mysid and gammarid amphipod of sample 20090716-1*

From the results presented in Table 6 it is evident that zooplankton was sampled in such small amounts that it is impossible to perform quantitative analyses. Especially the mere absence of copepods from the samples is surprising. The density of copepods in the Wadden Sea typically ranges in the order of $10^2$ to $10^5$ ind.$m^{-3}$ in summer (Frans et al., 1992).

While the implementation of the Autonomous Plankton Sampler (APS) in a commercial ferry was successful and the technical performance of the system is reliable, the sampling efficiency of the APS must be improved. The built-in flow meter of the APS indicated a constant flow that should have been sufficient to capture significant amounts of copepods and other zooplankton organisms. Based on published literature values (Fransz et al., 1992), the amount of zooplankton organisms should have been higher than observed even during times of extremely low zooplankton density. The most likely explanation for the observed low sampling efficiency is that the design of the inflow prevents zooplankton organisms from entering the system. This could be caused either by escape behaviour of the organisms themselves, or by the hydrodynamic properties of the inflow opening, or by both.

### 3.2.2 Pilot mobile APS

An additional experimental flow-through system (i.e. APS housing, piping and pump) was built to be used in inflow experiments conducted at different platforms of opportunity (e.g. research vessels). The APS used on the MS *Vlieland* was installed on board of the small research vessel Zilvervisje, thus simulating almost identical sampling conditions. Different inflow designs (funnels, opening directions etc.) were studied. The aim of this effort was to identify the ultimate cause for the present low sampling efficiency of the APS and to develop a design of the system that allows the most quantitative sampling of zooplankton possible.

The results of the test on board of the Zilvervisje indicate that the adapted mobile APS system using a gauze funnel at the inflow opening yields zooplankton abundances in an order of magnitude realistic for the Wadden Sea (Figure 21). The main components of the zooplankton were copepods (mainly calanoids), and nauplius larvae of barnacles. Also cypris larvae of barnacles were present in relatively high numbers in the samples, as were zoëa larvae of crabs. Total zooplankton densities ranged approximately between 130 and 560 individuals per $m^3$, and copepod densities from about 60 to over 200 per $m^3$.

### 3.2.3 North Sea trial

The mobile system tested on vessel Zilvervisje was installed on research vessel Tridens, and samples were taken in the North Sea (see section 2.2.2). The installation functioned well, demonstrating that zooplankton could be sampled for periods of up to 10 hours without need of maintenance. After a maximum running time of 10 hours, the system was stopped due to harsh weather conditions. A preliminary inspection of the gauzes showed that zooplankton was probably sampled in high numbers. However, zooplankton samples were not analysed quantitatively due to limited budget, and because the sampled area was beyond the scope of the project. The test on the Tridens demonstrated that the APS with inflow funnel could be implemented in large vessels, and sampling was possible at sailing speeds of commercial vessels (up to 13 kn).

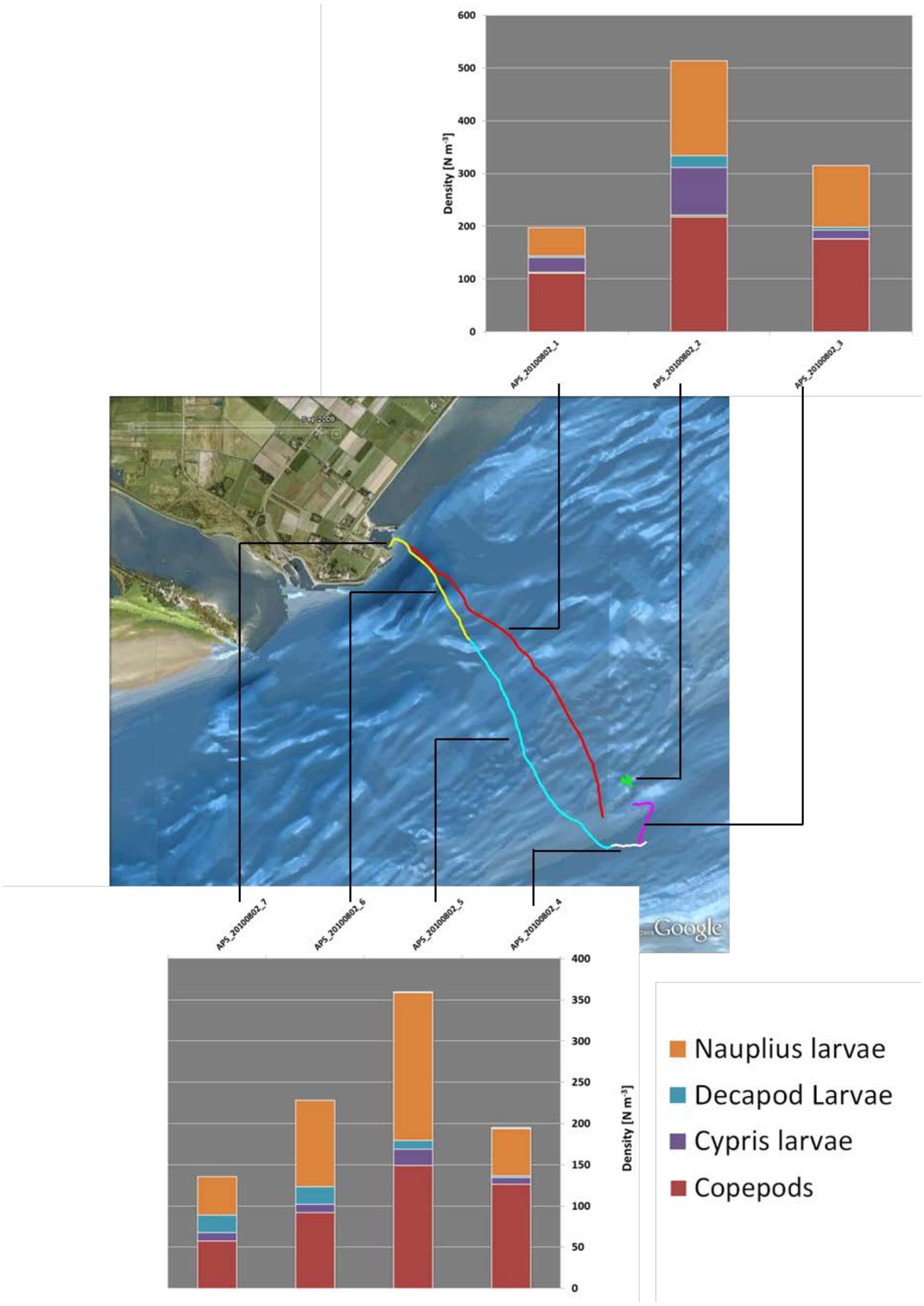


*Figure 21 Sampling transect near the NIOZ harbour in the Marsdiep area in the Wadden Sea, and analysed zooplankton samples from Zilvervisje (2010).*

### 3.2.4 Wadden Sea cruises

The system previously tested on RV Tridens was brought to the fishing vessel GO58 (see also section 2.2.2, Table 2), and applied in the Wadden Sea during a cruise in May 2011 (Annex VII).

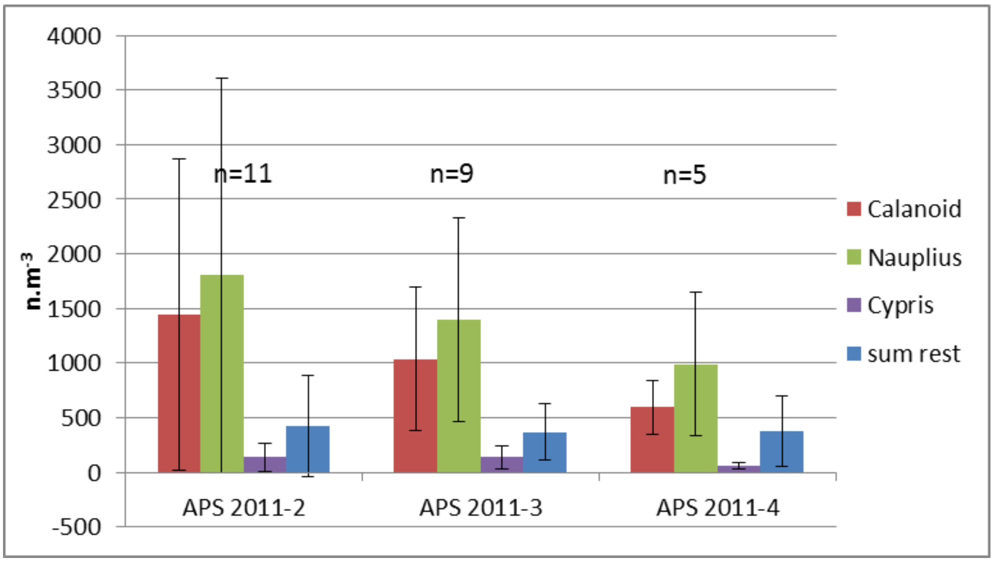


*Figure 22 Summary of average zooplankton densities from samples of different surveys with GO58 in the Wadden sea. Bars indicate standard deviations.*

Results in Figure 22 and Figure 23 show that different groups of zooplankton were sampled with the on-board system at GO58. Average copepod densities range between 500 and 1500 individuals per $m^3$, within the range of expected range (Frans et al., 1992) Also high densities of nauplius and cypris larvae were sampled. Other zooplankton comprised of larvae from different groups, including bivalve and gastropod molluscs, zoëa larvae of crabs, echinoderms, and polychaetes. Also numbers of cladocerans, and ostracods were caught. Other groups were only present in the samples in very low numbers, such as fish larvae, amphipods, and cumaceans.

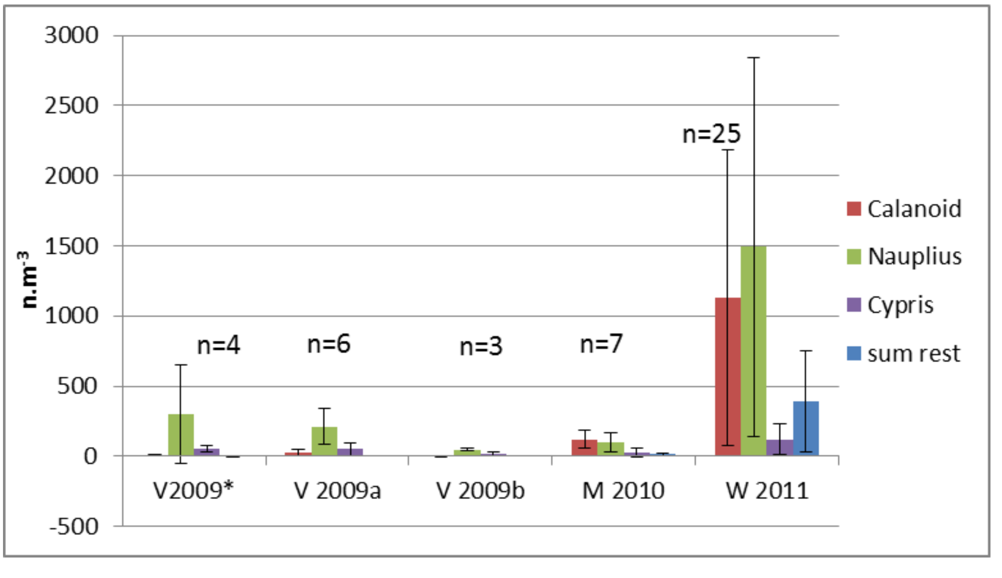


*Figure 23 Overview of all analysed zooplankton densities. Average values are presented, bars indicate standard deviations. See Table 2 for legend and Annex VII for data.*

# 4 Discussion and conclusions

## 4.1 Hydro acoustics

Installation of the echosounder in the hull of the TESO ferry was not successful due to excessive amounts of air bubbles under the hull, causing transmission loss in the echosounder. The acoustic surveys showed that fish schools in the Marsdiep area are found in the upper layers, almost 50% of all fish was found in the upper 6 meters. With a transducer at depth of 5 m, as it has been mounted during this study in the TESO, , most of the fish is out of reach of the acoustic equipment.
Transducer depth is also an issue in the acoustic survey carried out in this study. In every acoustic survey, some fish may be missed, because the transducer depth is 2 m. This effect may partly be compensated by the natural reflex of pelagic fish to escape the vessel by swimming downwards (Simmonds and Maclennon, 2005). In addition, the acoustic biomass estimates may be biased to an unknown degree, because the 38kHz transducer has a “near field” 9m according to the manufacturer. This means that echoes within this distance of the transducer are unpredictably shaped and cannot be properly calibrated. Nevertheless the accuracy of the acoustic estimate is probably higher than the estimate based on trawled area, because it is based on a much higher number of samples: the abundance estimate is calculated from the average of the fish densities in 56-194 samples of 0.5 nmi, whereas the number of trawls samples is (9-19).
Future monitoring of pelagic fish in the area could be carried out by survey by a vessel, similar as in this study. Another possibility is a fixed construction at the bottom of the Marsdiep with a transducer pointing towards the surface. Data could be transported by cable to ‘t Horntje or to Den Helder. Actual composition of the fish community (with swimbladder) could be verified by means of catch information from pelagic trawl hauls carried out on a regular basis. Distinction between fish with swimbladder and fish without swimbladder – in the Marsdiep area: clupeids and sandeel – may be possible by applying different frequencies, depending to what extend sandeel is mixed with clupeid schools (Korneliussen et al, 2008).

## 4.2 Zooplankton

The application of an on-board APS (Autonomous Plankton Sampler) system has shown to yield valuable information on zooplankton composition and densities. In contrast to the traditional CPR, which can only be towed in deeper waters, the on-board system enables automated sampling in shallow water bodies, such as the Wadden Sea. However, there are a number of pre-conditions that need to be met in the technical set-up, and in addition, the results from samplings should be interpreted with care.

It appeared from this study that the design of the water inlet system is of crucial importance for the efficiency for catching zooplankton at normal (relatively high) sailing speeds of ferries or commercial vessels. The application of a gauze funnel directed in the sailing direction of the ship yielded the best results. The shape and size of the funnel could be further optimized. Building such an inlet system on board of commercial vessels such as ferries may not always be allowed. Therefore, when developing a monitoring programme, equipping research vessels with an APS may be considered, or the use of mobile systems. Also sampling on moored systems could be considered, where the flow of the water current could be applied.
Although the APS system yielded realistic numbers of zooplankton during the final sampling campaigns, it is not yet known what the sampling efficiency of the APS system is, because parallel net samples were not taken. The question is whether the sampled numbers and species represent the natural composition or not. It is known from CPR data, that different species are caught with different efficiency, and for that reason, empirically established correction factors are applied to estimate zooplankton densities (Batten et

al., 2003). Therefore, a calibration with traditional sampling methods could be considered. However, time-series of the type of data presented in this report would be useful to detect relative changes in species composition, densities and seasonal trends. The detection of such relative changes would be highly valuable in any long-term monitoring programme.

Recommendations

- It is not possible to collect abundance data on pelagic fish with an echosounder mounted in the moon pool of the TESO: the pelagic schools in the Marsdiep area are so high in the water column that most of the schools are missed.
- Future monitoring of abundance of pelagic fish could be carried out by a set of echosounders with different frequencies mounted on a fixed construction at the bottom of the Marsdiep, pointed towards the surface.
- Actual composition of the pelagic fish composition can be verified by carrying out pelagic hauls on a regular basis.
- Zooplankton can be efficiently monitored by means of an on-board Autonomous Plankton Sampler on condition that an appropriate design of the water intake funnel is applied.
- Calibration of the APS is needed with traditional sampling methods to allow comparison with tow net data.

# Acknowledgements

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# References


Airoldi, L., M.W. Beck, 2007. Loss, status and trends for coastal marine habitats of Europe, in: Gibson, R.N., Atkinson, R.J.A., Gordon, J.D.M. (Eds.), Oceanography and Marine Biology, Vol 45, pp. 345-405.

Batten S.D., R. Clark, J. Flinkman, G. Hays, E. John, A.W.G. John, T. Jonas, J.A. Lindley, D.P. Stevens & A. Walne, 2003. CPR sampling: the technical background, materials and methods, consistency and comparability. Progress in Oceanography 58 (2003) 193–215.

Beaugrand, G., K.M. Brander, J.A. Lindley, S. Souissi and P. C. Reid, 2003. Plankton effect on cod recruitment in the North Sea. Nature 426: 661-664.

Beck, M.W., K.L. Heck, K.W. Able, D.L. Childers, D.B. Eggleston, B.M. Gillanders,B. Halpern, C.G. Hays, K. Hoshino, T.J. Minello, R.J. Orth, P.F. Sheridan & M.R. Weinstein, 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51, 633-641.

Bolle, L.J., R. Dapper, J.I. Witte & H.W. Van der Veer, 1994. Nursery grounds of dab (*Limanda limanda* L) in the southern North Sea. Netherlands Journal of Sea Research 32, 299-307.

Breine, J., J. Maes, F. Ollevier & M. Stevens, 2011. Fish assemblages across a salinity gradient in the Zeeschelde estuary (Belgium). Belgian Journal of Zoology 141, 21-44.

Couperus, A.S. & I. Tulp, 2005. Vissen onder Bruinvissen en roodkeelduikers. Verslag van een kustsurvey in maart 2005.

Daenhardt, A. & P.H. Becker, 2011. Herring and Sprat Abundance Indices Predict Chick Growth and Reproductive Performance of Common Terns Breeding in the Wadden Sea. Ecosystems 14, 791-803.

Daenhardt, A., T. Fresemann & P.H. Becker, 2011. To eat or to feed? Prey utilization of Common Terns Sterna hirundo in the Wadden Sea. Journal of Ornithology 152, 347-357.
ICES, 2012. Report of the Workshop on the Value of Coastal Habitats for Exploited Species (WKVHES), 25-29 June 2012, Copenhagen, Denmark.

Fässler, S.M.M., R. Santos, N. García-Núñez & P.G. Fernandes, 2011. Multifrequency backscattering properties of Atlantic herring (*Clupea harengus*) and Norway pout (*Trisopterus esmarkii*). Canadian Journal of Fisheries and Aquatic Sciences, 2007, 64: 362-374.

Fransz H.G., S.R. Gonzalez, , G.C. Cadee & F.C. Hansen, 1992. Long-term change of *Temora longicornis* (copepoda, calanoida) abundance in a Dutch tidal inlet (Marsdiep) in relation to eutrophication Netherlands Journal of Sea Research 30: 23-32.

Grift, R.,A.S. Couperus, M.S., Ybema & N.S.H. Tiën, 2004. Base line studies North Sea wind farms: biological data pelagic fish. Report Nr. C031/04.

Korneliussen, R.J & E. Ona, 2004. Verified acoustic identification of Atlantic mackerel. ICES CM 2004/R:20.

Korneliussen, R. J., N. Diner, E. Ona, L. Berger & P. Fernandes, 2008. Proposals for the collection of multifrequency acoustic data. ICES Journal of Marine Science: Journal du Conseil 65(6): 982-994.

Philippart, C.J.M., J.J. Beukema, G.C. Cadeé, R. Dekker, P.W. Goedhart, J.M. van Iperen, M.F. Leopold & P.M.J. Herman, 2007. Impacts of nutrient reduction on coastal communities. Ecosystems 10.1007/s10021-006-9006-7.

Simmonds, J. & D. MacLennan, 2005. Fisheries acoustics – Theory and Practice (Second Edition. Oxford: Blackwell Scienc Ltd.: 437 pp.

Tulp, I., L.J. Bolle & A.D. Rijnsdorp, 2008. Signals from the shallows: In search of common patterns in long-term trends in Dutch estuarine and coastal fish. Journal of Sea Research 60, 54-73.

Van der Veer, H.W., J. Koot, G. Aarts, R. Dekker, W. Diderich, V. Freitas & J.I.J. Witte, 2011. Long-term trends in juvenile flatfish indicate a dramatic reduction in nursery function of the Balgzand intertidal, Dutch Wadden Sea. Marine Ecology-Progress Series 434, 143-154.

Vasconcelos, R.P., O. Le Pape, D.B. Eggleston & I. Tulp, 2014. Quantitative assessment of the value of coastal habitats for marine exploited marine fish and invertebrates: a selective review. ICES J. Mar. Sci. 71: 638-647.

# Justification

Report: C094/13
Project Number: 4306300401

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: O.G. Bos
Researcher

Signature:

Date: January, 2016

Approved: L.J.W. Hoof
Head of Fisheries department

Signature:

Date: January, 2016

# Annex I: Calibration of echosounders

```
# Calibration  Version   2.1.0.12
#
# Date:  17-5-2010
#
# Comments:
#   teso april 2010 5th
#
# Reference Target:
#   TS                  -33.60 dB      Min. Distance         8.00 m
#   TS Deviation          5.0 dB       Max. Distance        11.00 m
#
# Transducer:  ES38B  Serial No.   345
#   Frequency           38000 Hz       Beamtype              Split
#   Gain                25.57 dB       Two Way Beam Angle   -20.6 dB
#   Athw. Angle Sens.       21.90      Along. Angle Sens.      21.90
#   Athw. Beam Angle     6.97 deg      Along. Beam Angle    7.01 deg
#   Athw. Offset Angle   0.00 deg      Along. Offset Angle -0.08 deg
#   SaCorrection        -0.56 dB       Depth                0.00  m
#
# Transceiver:  GPT  38 kHz 009072017a3b 2-1 ES38B
#   Pulse Duration       1.024 ms      Sample Interval     0.190   m
#   Power                2000  W       Receiver Bandwidth   2.43 kHz
#
# Sounder Type:
#   EK60 Version  2.2.0
#
# TS Detection:
#   Min. Value           -50.0 dB      Min. Spacing           100 %
#   Max. Beam Comp.        6.0 dB      Min. Echolength         80 %
#   Max. Phase Dev.          8.0       Max. Echolength        180 %
#
# Environment:
#   Absorption Coeff.   7.1 dB/km      Sound Velocity     1484.5 m/s
#
# Beam Model results:
#   Transducer Gain    = 25.51 dB      SaCorrection       = -0.55 dB
#   Athw. Beam Angle   = 6.78 deg      Along. Beam Angle  = 6.87 deg
#   Athw. Offset Angle = 0.03 deg      Along. Offset Angle=-0.05 deg
#
# Data deviation from beam model:
#   RMS =    0.17 dB
#   Max =    0.38 dB  No. =   204  Athw. =  3.6 deg  Along =  2.0 deg
#   Min =   -0.90 dB  No. =     6  Athw. =  0.6 deg  Along = -0.7 deg
#
# Data deviation from polynomial model:
#   RMS =    0.12 dB
#   Max =    0.36 dB  No. =   246  Athw. =  0.8 deg  Along = -4.9 deg
```

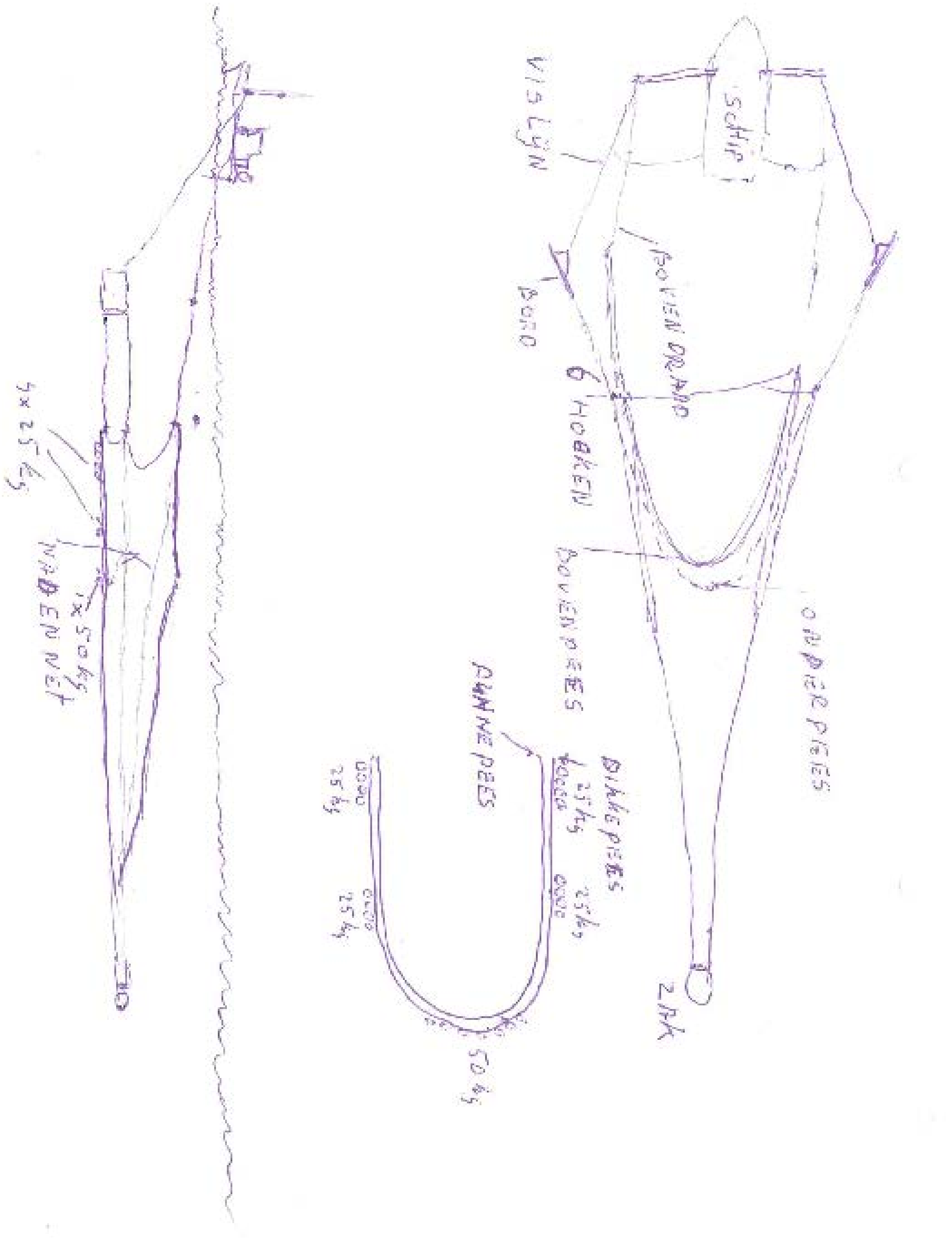
#    Min =   -0.76 dB  No. =     6  Athw. =  0.6 deg  Along = -0.7 deg

```
#  Calibration  Version   2.1.0.12
#
#  Date:  10/11/2010
#
#  Comments:
#    calibration TOR kade 111010 #2
#
#  Reference Target:
#    TS                  -33.00 dB       Min. Distance          8.50 m
#    TS Deviation           5.0 dB       Max. Distance         11.50 m
#
#  Transducer:  ES38B  Serial No.   31010
#    Frequency            38000 Hz       Beamtype               Split
#    Gain                 24.57 dB       Two Way Beam Angle   -20.6 dB
#    Athw. Angle Sens.       21.90       Along. Angle Sens.      21.90
#    Athw. Beam Angle     7.02 deg       Along. Beam Angle    7.04 deg
#    Athw. Offset Angle  -0.02 deg       Along. Offset Angle -0.06 deg
#    SaCorrection         -0.60 dB       Depth                 0.00  m
#
#  Transceiver:  GPT  38 kHz 009072017a3b 1-1 ES38B
#    Pulse Duration       1.024 ms       Sample Interval     0.192   m
#    Power                2000  W        Receiver Bandwidth   2.43 kHz
#
#  Sounder Type:
#    EK60 Version  2.2.1
#
#  TS Detection:
#    Min. Value           -50.0 dB       Min. Spacing           100 %
#    Max. Beam Comp.        6.0 dB       Min. Echolength         80 %
#    Max. Phase Dev.          8.0        Max. Echolength        180 %
#
#  Environment:
#    Absorption Coeff.   6.4 dB/km       Sound Velocity     1503.3 m/s
#
#  Beam Model results:
#    Transducer Gain    = 24.84 dB       SaCorrection       = -0.61 dB
#    Athw. Beam Angle   = 6.92 deg       Along. Beam Angle  = 6.97 deg
#    Athw. Offset Angle = 0.06 deg       Along. Offset Angle=-0.06 deg
#
#  Data deviation from beam model:
#    RMS =    0.11 dB
#    Max =    0.26 dB  No. =   312  Athw. =  3.2 deg  Along =  3.5 deg
#    Min =   -0.41 dB  No. =   215  Athw. =  1.0 deg  Along = -4.9 deg
#
#  Data deviation from polynomial model:
#    RMS =    0.06 dB
#    Max =    0.18 dB  No. =   343  Athw. =  3.2 deg  Along = -3.6 deg
#    Min =   -0.25 dB  No. =   311  Athw. =  3.0 deg  Along =  2.7 deg
```

```
# Calibration Version 2.1.0.12
#
# Date: 15-4-2011
#
# Comments:
#   Europort 150411 38kHz 256us_2
#
# Reference Target:
#   TS                  -33.60 dB      Min. Distance        8.00 m
#   TS Deviation          5.0 dB       Max. Distance       11.00 m
#
# Transducer: ES38B Serial No. 31010
#   Frequency           38000 Hz       Beamtype             Split
#   Gain                23.11 dB       Two Way Beam Angle  -20.6 dB
#   Athw. Angle Sens.      21.90       Along. Angle Sens.     21.90
#   Athw. Beam Angle     6.83 deg      Along. Beam Angle   6.90 deg
#   Athw. Offset Angle   0.05 deg      Along. Offset Angle -0.03 deg
#   SaCorrection        -0.65 dB       Depth                0.00 m
#
# Transceiver: GPT 38 kHz 00907205fb91 1-1 ES38B
#   Pulse Duration      0.256 ms       Sample Interval     0.047 m
#   Power               2000 W         Receiver Bandwidth  3.68 kHz
#
# Sounder Type:
#   EK60 Version 2.2.0
#
# TS Detection:
#   Min. Value          -38.0 dB       Min. Spacing          100 %
#   Max. Beam Comp.       6.0 dB       Min. Echolength        80 %
#   Max. Phase Dev.       8.0          Max. Echolength       180 %
#
# Environment:
#   Absorption Coeff.  7.2 dB/km       Sound Velocity    1480.4 m/s
#
# Beam Model results:
#   Transducer Gain    = 23.11 dB      SaCorrection      = -0.69 dB
#   Athw. Beam Angle   = 6.90 deg      Along. Beam Angle  = 6.88 deg
#   Athw. Offset Angle = 0.04 deg      Along. Offset Angle=-0.04 deg
#
# Data deviation from beam model:
#   RMS =   0.16 dB
#   Max =   0.36 dB  No. =  139  Athw. = 3.0 deg  Along =  3.4 deg
#   Min =  -0.62 dB  No. =  156  Athw. = 4.8 deg  Along = -0.5 deg
#
# Data deviation from polynomial model:
#   RMS =   0.10 dB
#   Max =   0.38 dB  No. =  153  Athw. = 4.4 deg  Along = -2.0 deg
#   Min =  -0.34 dB  No. =  155  Athw. = 4.4 deg  Along = -0.9 deg
```

```
#  Calibration  Version   2.1.0.12
#
#  Date:  3-10-2011
#
#  Comments:
#    38 kHz 512 us Max power 3de Kalibratie
#
#  Reference Target:
#    TS                  -33.60 dB       Min. Distance          5.10 m
#    TS Deviation           7.0 dB       Max. Distance          6.40 m
#
#  Transducer:  ES38B  Serial No.   38
#    Frequency            38000 Hz       Beamtype               Split
#    Gain                 24.28 dB       Two Way Beam Angle   -20.6 dB
#    Athw. Angle Sens.       21.90       Along. Angle Sens.      21.90
#    Athw. Beam Angle     6.84 deg       Along. Beam Angle    6.93 deg
#    Athw. Offset Angle   0.07 deg       Along. Offset Angle  0.03 deg
#    SaCorrection         -0.85 dB       Depth                  0.00  m
#
#  Transceiver:  GPT  38 kHz 00907205fb91 3-1 ES38B
#    Pulse Duration       0.512 ms       Sample Interval     0.097   m
#    Power                2000  W        Receiver Bandwidth   3.28 kHz
#
#  Sounder Type:
#    EK60 Version  2.2.0
#
#  TS Detection:
#    Min. Value           -45.0 dB       Min. Spacing            60 %
#    Max. Beam Comp.        6.0 dB       Min. Echolength         80 %
#    Max. Phase Dev.          11.8       Max. Echolength        180 %
#
#  Environment:
#    Absorption Coeff.   6.7 dB/km       Sound Velocity     1510.0 m/s
#
#  Beam Model results:
#    Transducer Gain    = 24.40 dB       SaCorrection       = -0.81 dB
#    Athw. Beam Angle   = 6.97 deg       Along. Beam Angle  = 7.00 deg
#    Athw. Offset Angle = 0.04 deg       Along. Offset Angle= 0.01 deg
#
#  Data deviation from beam model:
#    RMS =    0.13 dB
#    Max =    0.29 dB  No. =   296  Athw. = -3.0 deg  Along = -3.3 deg
#    Min =   -0.43 dB  No. =   267  Athw. =  4.5 deg  Along =  1.2 deg
#
#  Data deviation from polynomial model:
#    RMS =    0.08 dB
#    Max =    0.19 dB  No. =    15  Athw. =  0.2 deg  Along =  3.2 deg
#    Min =   -0.28 dB  No. =   267  Athw. =  4.5 deg  Along =  1.2 deg
```

## Annex II: Drawing of a semi pelagic net “Zwever”.

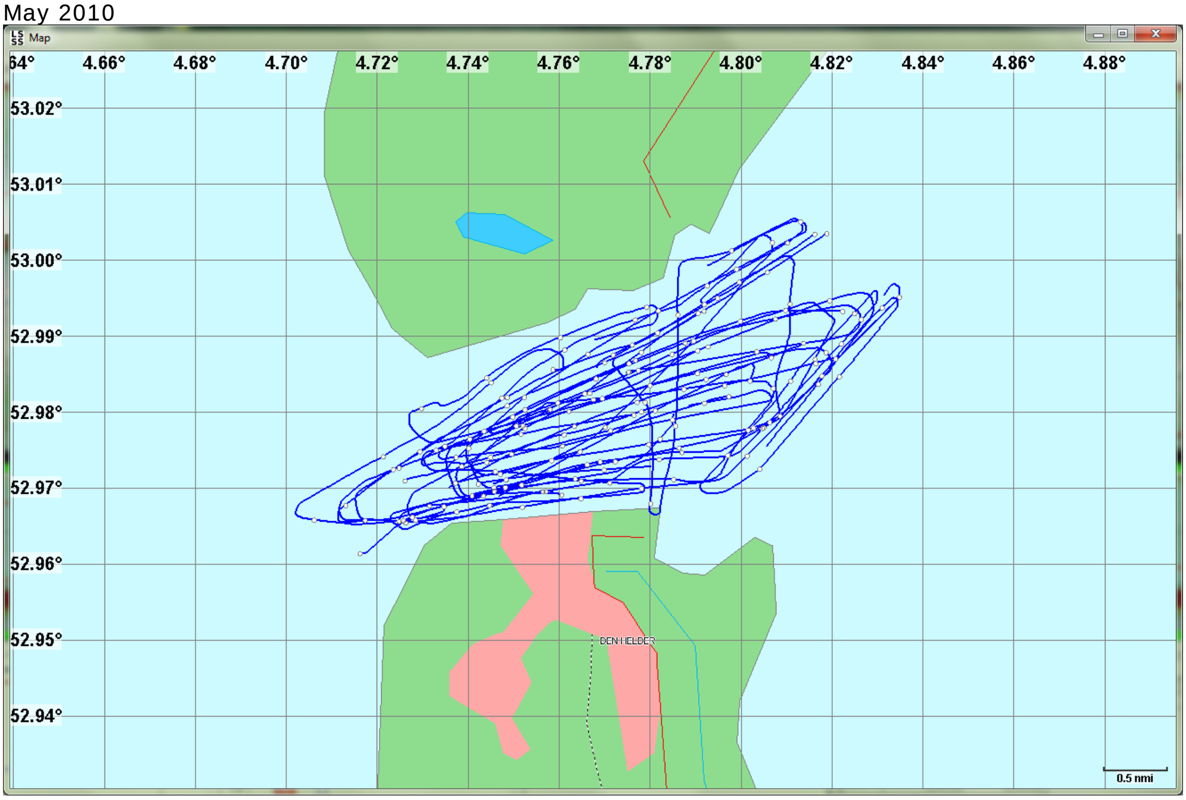


## Annex III: Geographical positions (longitude, latitude) defining the Marsdiep polygon for abundance estimation (degrees. decimalized degrees)

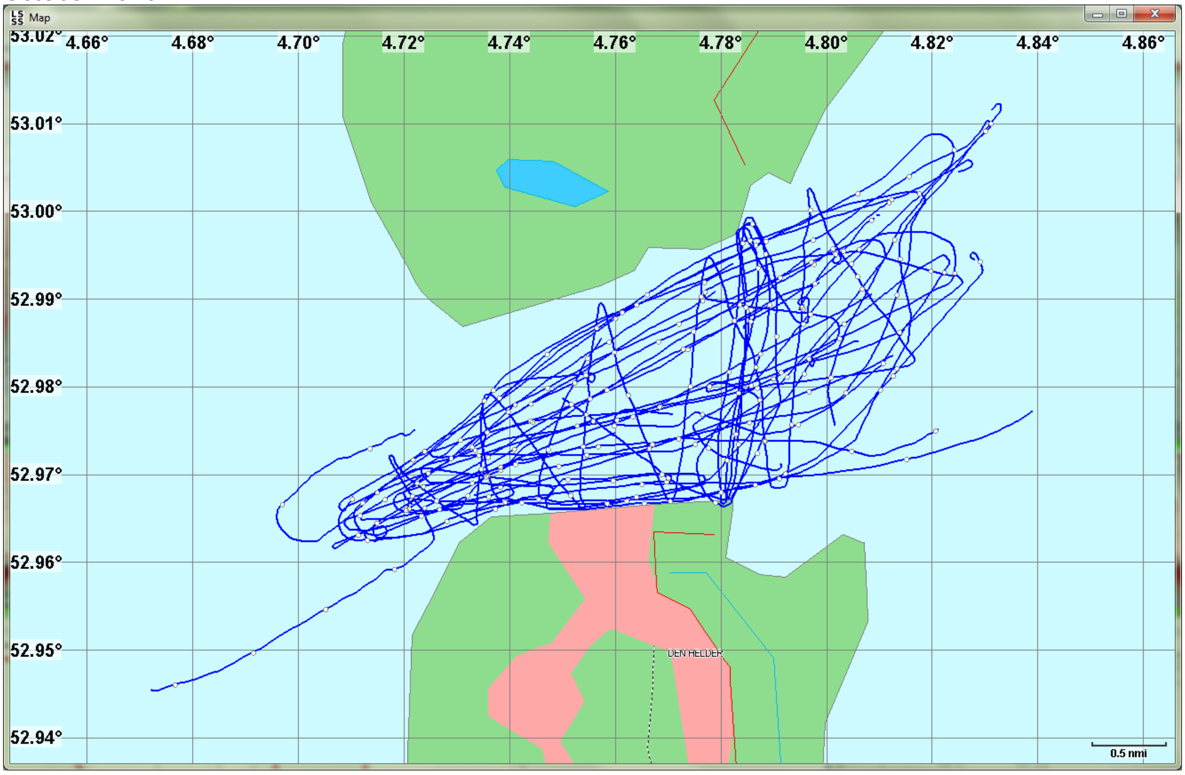
```
4.73391900656,52.978781243
4.7340762812,52.9671423251
4.75452303834,52.9660413486
4.77072313697,52.9669850234
4.79054074149,52.9685578509
4.81476227915,52.9822414472
4.80375248685,53.0042610048
4.79667477674,53.0017445024
4.77811542339,52.9946667653
4.75751139161,52.989476459
4.73391900656,52.978781243
```

# Annex IV: Cruise tracks during the Acoustic surveys

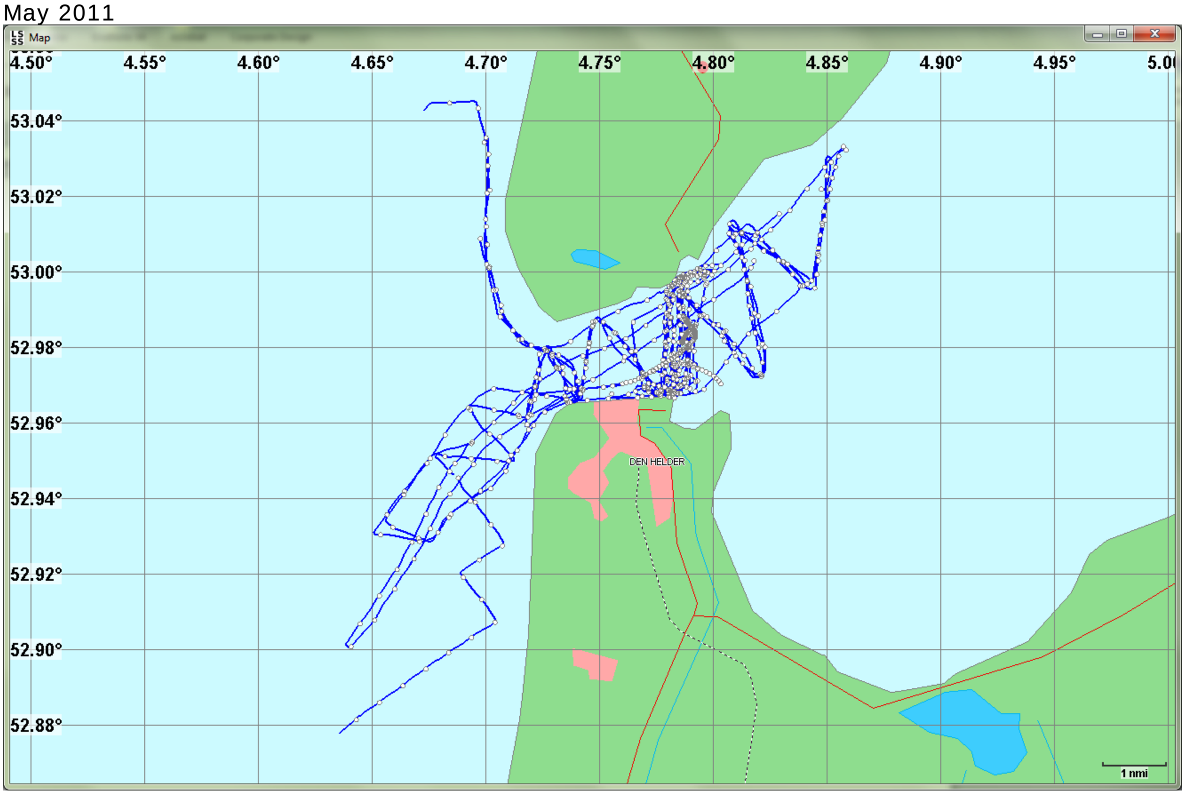
May 2010




October 2010



May 2011




October 2011
[not available]

# Annex V: Trawl hauls: haul data (date, time), start and positions, numbers and weight per hour trawling.

## a. Table catch – main species. Weight (g) (numbers)

| haul number | UTC | year | month | day | latitude shooting | longitude shooting | latitude hauling | longitude hauling | *Ammodytes tobianus* sandeel | *Aphia minuta* transparent goby | *Clupea harengus* herring | *Cyclopterus lumpus* lumpsucker | *Engraulis encrasicolus* anchovy | *Gasterosteus aculeatus* stickleback | *Hyperoplus lanceolatus* greater sandeel | *Osmerus eperlanus* smelt | *Sardina pilchardus* pilchard | *Scomber scombrus* mackerel | *Sprattus sprattus* sprat | *Syngnathus rostellatus* Nilsson's pipefish |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1007 | 2010 | 5 | 18 | 52.97533 | 4.767 | 52.97067 | 4.73717 | 50256(7250) | | 196(8) | | 9824(556) | | 94(3) | | | 459(2) | 393158(106108) | |
| 2 | 1307 | 2010 | 5 | 18 | 52.98783 | 4.81983 | 52.97683 | 4.795 | 45038(7631) | | 2388(169) | | 15843(1046) | | | | | | 49966(15508) | |
| 3 | 1440 | 2010 | 5 | 18 | 52.99167 | 4.77433 | 52.98317 | 4.75233 | 929(184) | | 1989(283) | | 114(7) | 10(7) | 18(1) | | | | 621(176) | 12(50) |
| 4 | 1818 | 2010 | 5 | 18 | 52.98117 | 4.7935 | 52.97983 | 4.7825 | 14543(2346) | | 3706(579) | | 13179(662) | 157(76) | | | | | 216(78) | 33(227) |
| 5 | 601 | 2010 | 5 | 19 | 52.984 | 4.76717 | 52.99667 | 4.80333 | 82543(9280) | | 2789(824) | 540(8) | 3385(192) | 10(8) | 233(8) | | | | | 11(48) |
| 6 | 749 | 2010 | 5 | 19 | 52.9695 | 4.7625 | 52.96883 | 4.7525 | 438(60) | | 10530(2880) | | 740(37) | | 25(1) | | | 3202(17) | 74451(21120) | |
| 7 | 924 | 2010 | 5 | 19 | 52.99183 | 4.82917 | 52.9815 | 4.81167 | 47383(8696) | | 13695(3478) | | 22987(1304) | 65(65) | 241(6) | | | 871(3) | 256022(75826) | |
| 8 | 1128 | 2010 | 5 | 19 | 52.99783 | 4.79917 | 53.0045 | 4.81917 | 283(46) | | 81(11) | | 250(18) | 23(24) | 361(10) | | | | 6873(1859) | 2(8) |
| 9 | 1228 | 2010 | 5 | 19 | 52.98683 | 4.772 | 52.99083 | 4.78383 | 1361(255) | | 49(3) | | 2559(126) | | 211(21) | | | 173(1) | 28640(7251) | 2(6) |
| 10 | 1338 | 2010 | 5 | 19 | 52.95967 | 4.70433 | 52.96317 | 4.72033 | 11644(2426) | | | | 23554(1120) | | 106(3) | | | 7054(35) | 1203360(349603) | |
| 11 | 1502 | 2010 | 5 | 19 | 52.976 | 4.794 | 52.983 | 4.80867 | 242(54) | | 29096(7656) | | 48205(3915) | 3(1) | 65(5) | | | | 5288(1305) | 806(3306) |
| 12 | 655 | 2010 | 5 | 20 | 52.97383 | 4.77933 | 52.97283 | 4.76817 | 6084(907) | | 8487(3767) | | 6087(357) | 14(16) | | | | | | 20(97) |
| 13 | 825 | 2010 | 5 | 20 | 52.97317 | 4.74967 | 52.98617 | 4.79317 | | | 5479(1480) | 51(1) | 1887(132) | | 176(6) | | | | 3734(1085) | 1(6) |
| 14 | 929 | 2010 | 5 | 20 | 52.97133 | 4.75583 | 52.968 | 4.74133 | 9533(1728) | | 3166(1085) | | 6124(342) | | | | | | 323838(87845) | |
| 15 | 1132 | 2010 | 5 | 20 | 52.97867 | 4.8085 | 52.9885 | 4.823 | 950(225) | | 68(1) | | 1968(90) | 156(152) | 251(13) | | | | 16204(4390) | |
| 16 | 1237 | 2010 | 5 | 20 | 52.98417 | 4.768 | 52.99017 | 4.78917 | 6638(1023) | 2(1) | | | 1295(59) | | 270(7) | | | 6576(34) | 18083(4239) | |
| 17 | 1401 | 2010 | 5 | 20 | 52.98667 | 4.75933 | 52.98783 | 4.76567 | 1800(420) | | 1221(48) | | 1271(90) | | 16(3) | | | | 76151(21386) | 2(6) |
| 18 | 1629 | 2010 | 5 | 20 | 52.9705 | 4.74533 | 52.97867 | 4.76533 | 11968(2167) | | 12922(3478) | | 8105(516) | | 262(6) | | | | 27323(9072) | 1(6) |
| 1 | 734 | 2010 | 10 | 12 | 52.97433 | 4.73983 | 52.98933 | 4.77583 | | | 17239(3558) | | 73(123) | | 648(40) | 48(40) | | | 101477(9426) | 0(3) |
| 2 | 913 | 2010 | 10 | 12 | 52.98983 | 4.82767 | 52.98233 | 4.80967 | 7(1) | | 5482(1041) | 18(1) | 36(66) | | 125(8) | | | 202(3) | 228140(21276) | 5(32) |
| 3 | 1017 | 2010 | 10 | 12 | 52.96933 | 4.718 | 52.97217 | 4.81667 | 13(1) | | 4705(1127) | | 18025(8160) | | 41(3) | | 41127(14401) | 886(15) | 560090(52480) | |
| 4 | 1239 | 2010 | 10 | 12 | 52.98117 | 4.77167 | 52.98367 | 4.77867 | | | 1075(192) | 25(2) | 1157(742) | | 16(1) | | 1054(445) | 158(2) | 199527(18189) | 2(37) |
| 5 | 1344 | 2010 | 10 | 12 | 52.96517 | 4.72983 | 52.9695 | 4.73783 | | | 7692(2463) | 11(1) | | | 14(1) | | 132(58) | | 153285(19749) | 8(58) |
| 6 | 1520 | 2010 | 10 | 12 | 52.97967 | 4.73833 | 52.98483 | 4.75183 | | 14(58) | 14028(2642) | 11(1) | | | | | | | 128066(14927) | 8(59) |
| 7 | 1716 | 2010 | 10 | 12 | 52.969 | 4.76267 | 52.96733 | 4.7415 | | | 70990(16063) | | | 16(60) | | 566(501) | | | 13966(1606) | 7(47) |
| 8 | 724 | 2010 | 10 | 13 | 52.99367 | 4.77867 | 52.988 | 4.76467 | 22(7) | | 3989(1294) | 3(1) | 26(76) | | 24(2) | 5(4) | 21311(12409) | | 390445(42761) | 2(14) |
| 9 | 906 | 2010 | 10 | 13 | 53.0095 | 4.82733 | 53.002 | 4.81383 | 1(1) | | 60928(11124) | 11(1) | 14(2) | | 1(1) | 8(2) | 1(1) | | 142534(10794) | 7(101) |
| 10 | 1025 | 2010 | 10 | 13 | 52.96617 | 4.72017 | 52.9755 | 4.745 | | | 3647(1118) | 23(2) | 1225(736) | | | | 16164(6601) | 134(2) | 482353(48095) | 2(7) |
| 11 | 1238 | 2010 | 10 | 13 | 52.99117 | 4.79733 | 52.99917 | 4.80917 | 23(1) | 1(16) | 74(6) | | 500(592) | | | | 1445(794) | | 30763(3145) | 0(3) |
| 12 | 1356 | 2010 | 10 | 13 | 52.97567 | 4.76167 | 52.9765 | 4.77383 | | 2(10) | 18(2) | 26(1) | 51(59) | 1(1) | 32(3) | | 8661(5699) | | 233467(30272) | 1(8) |
| 13 | 1520 | 2010 | 10 | 13 | 52.98767 | 4.80483 | 52.9935 | 4.81667 | | | 11719(2421) | 82(3) | | 0(1) | | 2(2) | 1190(961) | | 61616(6846) | 1(4) |
| 14 | 1741 | 2010 | 10 | 13 | 52.976 | 4.78767 | 52.9905 | 4.7845 | | | 4570(903) | 18(1) | | 9(21) | | 37(5) | 599(456) | | 15104(1940) | 2(8) |
| 15 | 1841 | 2010 | 10 | 13 | 52.972 | 4.74017 | 52.98017 | 4.7925 | 4(1) | | 1657(343) | | | | | 2(2) | 238(119) | | 3989(487) | |
| 16 | 714 | 2010 | 10 | 14 | 52.977 | 4.83817 | 52.97467 | 4.82367 | 15(4) | | 29308(5725) | 18(2) | 3(4) | | 9(1) | 245(204) | | | 102185(13312) | 38(196) |
| 17 | 902 | 2010 | 10 | 14 | 52.983 | 4.8125 | 52.97283 | 4.80233 | 23(4) | 123(498) | 3681(1012) | 18(1) | 272(562) | 4(6) | 216(33) | 8(7) | 49255(28865) | | 373455(45787) | 6(29) |
| 18 | 1139 | 2010 | 10 | 14 | 52.99183 | 4.79817 | 53.00283 | 4.81833 | 13(1) | 69(278) | 651(18) | 44(2) | 26(20) | | 122(9) | 1(1) | 17446(8340) | 114(2) | 390371(39200) | 1(6) |
| 19 | 1306 | 2010 | 10 | 14 | 52.9705 | 4.70483 | 52.95383 | 4.67733 | 38(45) | 3(45) | 1332(190) | | 978(801) | 11(45) | 17(3) | | 16811(8010) | 678(11) | 18513(2092) | 9(47) |
| 1 | 640 | 2011 | 5 | 3 | 53.001 | 4.80617 | 53.016 | 4.82933 | 1607(438) | | 3945(222) | | 2430(122) | 2(2) | 1212(56) | | | 616(3) | 39256(15466) | 26(94) |
| 2 | 958 | 2011 | 5 | 3 | 52.963 | 4.71517 | 52.96583 | 4.72317 | 2384(688) | 53(63) | 5284(473) | | 469(25) | 19(31) | 18(1) | | | | 17087(5750) | 1(4) |
| 3 | 1208 | 2011 | 5 | 3 | 53.028 | 4.7005 | 53.0135 | 4.6995 | 14304(2933) | 99(89) | 7955(719) | | 374(20) | 94(89) | | 36(4) | | | 57176(26880) | 210(622) |
| 4 | 1433 | 2011 | 5 | 3 | 52.96733 | 4.77367 | 52.967 | 4.76333 | 18253(7980) | | 902(310) | | 862(47) | 268(305) | 56(1) | 6(1) | | 3453(18) | 138403(74848) | 81(275) |
| 5 | 1833 | 2011 | 5 | 3 | 53.03483 | 4.66917 | 53.04633 | 4.68733 | 38045(4200) | | 20805(1603) | | 631(37) | | | | | 3140(14) | 25950(6267) | |
| 6 | 1732 | 2011 | 5 | 4 | 52.9795 | 4.78233 | 52.97717 | 4.77583 | 21979(2857) | | 51185(4007) | | 3996(220) | | 68(2) | | | 1190(6) | 542285(221486) | |
| 7 | 636 | 2011 | 5 | 5 | 53.01467 | 4.83267 | 53.004 | 4.82583 | 358(64) | 2(1) | 478(44) | | 4737(267) | 27(23) | 67(3) | | | | 6344(2858) | 350(1260) |
| 8 | 818 | 2011 | 5 | 5 | 52.9875 | 4.80317 | 52.9925 | 4.82083 | 20748(4190) | | 97(10) | | 408(23) | 3797(3143) | 1896(50) | | | 1308(5) | 88776(35095) | |
| 9 | 956 | 2011 | 5 | 5 | 52.9745 | 4.7325 | 52.9765 | 4.73767 | 4541(1200) | | 4758(331) | | 2513(140) | | 227(9) | | | 1047(4) | 930897(372400) | |
| 10 | 1325 | 2011 | 5 | 5 | 53.01183 | 4.8375 | 52.99467 | 4.80583 | 179(47) | | 799(78) | | 6240(385) | 12(7) | | 10(1) | | | 13204(6250) | 103(370) |
| 11 | 1525 | 2011 | 5 | 5 | 52.98583 | 4.801 | 52.99017 | 4.83133 | 41118(7807) | | 149(16) | | 2769(173) | | 317(7) | | | | 4902(2567) | 111(428) |
| 12 | 1811 | 2011 | 5 | 5 | 52.9495 | 4.68433 | 52.94667 | 4.6825 | 84(15) | | 531(45) | | 718(41) | | 68(2) | | | | 102425(42000) | |
| 1 | 905 | 2011 | 10 | 18 | 52.98283 | 4.75667 | 52.98033 | 4.74783 | 43(3) | | 2803(228) | | | | 115(5) | | | | 291203(10980) | 1(1) |
| 2 | 1240 | 2011 | 10 | 18 | 54.02667 | 4.8395 | 54.02667 | 4.81133 | | | | | 6(3) | 4(3) | 4(3) | | | | 189(8) | 0(1) |
| 3 | 1446 | 2011 | 10 | 18 | 52.97517 | 4.78667 | 52.98033 | 4.802 | | | 69878(6890) | 70(5) | | | 39(1) | | | | 206152(8857) | |
| 4 | 634 | 2011 | 10 | 19 | 52.99433 | 4.8 | 52.98817 | 4.78617 | | | 1417(128) | 82(4) | 1(1) | | 75(3) | 40(1) | 6(1) | | 170467(8036) | |
| 5 | 840 | 2011 | 10 | 19 | 53.01167 | 4.8225 | 53.00633 | 4.8135 | | | 129(2) | 44(2) | | | 50(2) | | | | 284393(11291) | 1(2) |
| 6 | 630 | 2011 | 10 | 20 | 53.004 | 4.841 | 53.0165 | 4.85083 | 45(3) | | 45(5) | 156(6) | | 4(4) | 75(4) | | | | 8258(480) | 1(2) |
| 7 | 733 | 2011 | 10 | 20 | 52.992 | 4.81217 | 53.0105 | 4.81767 | | | 100(8) | 156(8) | | 13(7) | 31(2) | | 4(1) | | 6268(472) | |
| 8 | 1105 | 2011 | 10 | 20 | 53.0015 | 4.81483 | 53.01683 | 4.83583 | 11(1) | | 137(13) | 62(4) | | 4(2) | 70(3) | 62(1) | | | 6246(265) | |
| 9 | 1324 | 2011 | 10 | 20 | 52.99033 | 4.79333 | 52.99533 | 4.79833 | | | 43(5) | 10(3) | | 116(81) | 68(19) | | | | 1621(69) | 1(2) |

b. Species incidental caught, numbers.

| total number | frequency of occurence | scientific name | English name |
|---|---|---|---|
| 31 | 1 | *Agonus cataphractus* | hooknose |
| 1 | 1 | *Alosa fallax* | twaite shad |
| 2 | 1 | *Arnoglossus laterna* | scalfish |
| 9 | 5 | *Atherina presbyter* | sand-smelt |
| 23 | 8 | *Belone belone* | garfish |
| 1 | 1 | *Chelon labrosus* | thick-lipped grey mullet |
| 3 | 2 | *Dicentrarchus labrax* | bass |
| 3 | 2 | *Eutrigla gurnardus* | grey gurnard |
| 1 | 1 | *Gymnocephalus cernuus* | ruffe |
| 20 | 8 | *Lampetra fluviatilis* | lampern |
| 4 | 3 | *Merlangius merlangus* | whiting |
| 5 | 3 | *Myoxocephalus scorpius* | bull-rout |
| 2 | 2 | *Platichthys flesus* | flounder |
| 3 | 2 | *Pleuronectes platessa* | plaice |
| 5 | 2 | *Pomatoschistus minutus* | sand goby |
| 11 | 6 | *Salmo trutta* | trout |
| 4 | 4 | *Sander lucioperca* | zander |
| 2 | 2 | *Solea solea* | sole |
| 3 | 2 | *Syngnathus acus* | greater pipefish |
| 28 | 1 | *Trachurus trachurus* | horse mackerel |

# Annex VI: Installation of the APS on MS "Vlieland"

Figure 1. Seawater intake with connector for APS bypass.

Figure 2. 1" Fitting (detail).

Figure 3. In the foreground envisaged installation place of APS. In the background seawater pipe with flange for re-introduction of APS water into the ship's seawater system.

Figure 4. Flange for re-introduction of APS water into the ship's seawater system.


Figure 5. MS Vlieland with located seawater inlet 1.5 m below water surface.

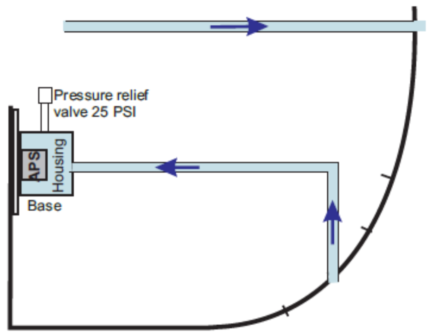



Figure 6. Frontal view of position of APS on board of MS Vlieland.

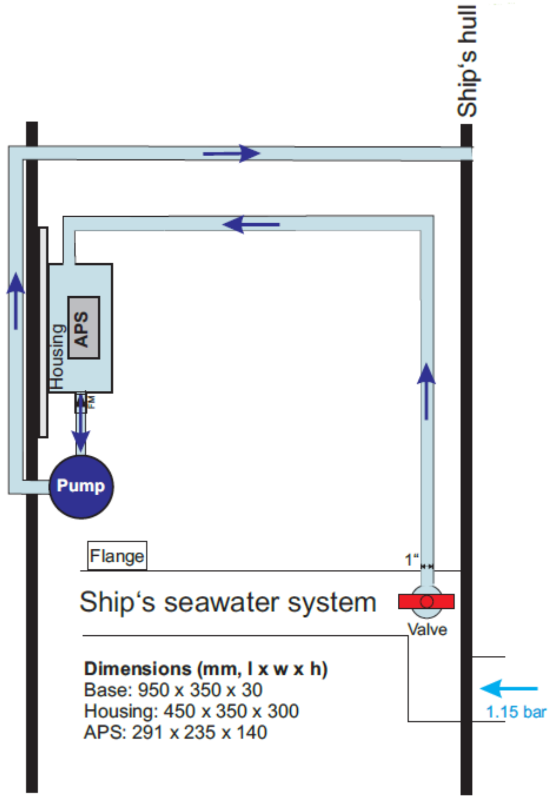



Figure 7. Top view of APS installation on board of MS Vlieland.

# Annex VII: Zooplankton samples and densities

| Row Labels | VLIELAND | 1 | APR 02 | APR 03 | APR 04 | APR 05 | 2 | APS 2009A1 | APS 2009A2 | APS 2009A3 | APS 2009A4 | APS 2009A5 | APS 2009A6 | 3 | APS 2009B1 | APS 2009B2 | APS 2009B3 | ZILVERVIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Filtered volume [m3] | 9.11 | 2.79 | 0.70 | 0.69 | 0.70 | 0.70 | 4.52 | 1.23 | 0.69 | 0.70 | 0.50 | 0.70 | 0.69 | 1.79 | 0.60 | 0.60 | 0.60 | 11.63 |
| Copepod | | | | | | | | | | | | | | | | | | |
| Calanoid | 140 | 24 | 8 | 12 | 2 | 2 | 112 | 12 | 30 | 7 | 6 | 13 | 44 | 4 | | | 4 | 883 |
| Harpacticoid | 4 | | | | | | 2 | | 1 | | | | 1 | 2 | 2 | | | 9 |
| Cyclopoid | 1 | | | | | | 1 | | | | 1 | | | | | | | |
| Nauplius | 1860 | 830 | 5 | 54 | 220 | 551 | 943 | 194 | 269 | 45 | 61 | 141 | 233 | 87 | 25 | 24 | 38 | 687 |
| Cypris | 382 | 147 | 58 | 35 | 18 | 36 | 208 | 18 | 39 | 16 | 13 | 28 | 94 | 27 | 2 | 7 | 18 | 175 |
| Bivalve Larva | | | | | | | | | | | | | | | | | | |
| Gastropod | | | | | | | | | | | | | | | | | | |
| Polychaete Larva | 4 | 3 | 3 | | | | 1 | 1 | | | | | | | | | | 2 |
| Crustacean nauplius | | | | | | | | | | | | | | | | | | 8 |
| Zoëa | 1 | | | | | | | | | | | | | 1 | 1 | | | 42 |
| Decapod Larva | 6 | | | | | | 4 | 1 | 3 | | | | | 2 | | | 2 | 14 |
| Shrimp larva | | | | | | | | | | | | | | | | | | |
| Fish Larva | 1 | | | | | | 1 | 1 | | | | | | | | | | |
| Cladoceran | | | | | | | | | | | | | | | | | | |
| Sea star | | | | | | | | | | | | | | | | | | |
| Appendicularia | | | | | | | | | | | | | | | | | | |
| Cumacean | 1 | | | | | | | | | | | | | 1 | | | 1 | 8 |
| Echinoderm larva | | | | | | | | | | | | | | | | | | |
| Decapod | 3 | | | | | | 3 | | 1 | 2 | | | | | | | | |
| Egg | 3 | 3 | 3 | | | | | | | | | | | | | | | |
| Ostracod | | | | | | | | | | | | | | | | | | |
| Amphipod | 1 | 1 | 1 | | | | | | | | | | | | | | | 1 |
| Foram | | | | | | | | | | | | | | | | | | |
| Crustacean Larva | 1 | | | | | | 1 | 1 | | | | | | | | | | |
| Noctiluca | | | | | | | | | | | | | | | | | | |
| Crustacean | 1 | 1 | | | | 1 | | | | | | | | | | | | 1 |
| Worm | | | | | | | | | | | | | | | | | | |
| Hydrozoa | | | | | | | | | | | | | | | | | | |
| Unidentified larva | | | | | | | | | | | | | | | | | | |
| Grand Total | 2409 | 1009 | 78 | 101 | 240 | 590 | 1276 | 228 | 343 | 70 | 81 | 182 | 372 | 124 | 30 | 31 | 63 | 1830 |

| Row Labels | 6 | APS_20100802_1 | APS_20100802_2 | APS_20100802_3 | APS_20100802_4 | APS_20100802_5 | APS_20100802_6 | APS_20100802_7 | GO58 | 8 | APS_20110502_03 | APS_20110502_04 | APS_20110502_05 | APS_20110502_06 | APS_20110502_07 | APS_20110502_08 | APS_20110502_09 | APS_20110502_10 | APS_20110502_11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Filtered volume [m3] | 11.63 | 6.80 | 0.80 | 0.96 | 0.96 | 0.96 | 0.96 | 0.19 | 25.79 | 25.79 | 0.52 | 1.83 | 1.82 | 1.80 | 0.75 | 0.42 | 0.88 | 1.79 | 0.88 |
| Copepod | | | | | | | | | 3 | 3 | | | 3 | | | | | | |
| Calanoid | 883 | 183 | 172 | 166 | 121 | 143 | 87 | 11 | 24607 | 24607 | 1464 | 1004 | 1404 | 1424 | 1624 | 1696 | 3004 | 1744 | 157 |
| Harpacticoid | 9 | 2 | 4 | 2 | | | 1 | | 34 | 34 | 3 | 7 | | | | 4 | | | |
| Cyclopoid | | | | | | | | | | | | | | | | | | | |
| Nauplius | 687 | 91 | 147 | 112 | 55 | 172 | 101 | 9 | 33388 | 33388 | 3032 | 2182 | 2200 | 2524 | 352 | 1548 | 3180 | 2388 | 547 |
| Cypris | 175 | 46 | 74 | 16 | 8 | 19 | 10 | 2 | 2888 | 2888 | 148 | 224 | 192 | 332 | 24 | 160 | 224 | 136 | 23 |
| Bivalve Larva | | | | | | | | | 5112 | 5112 | 28 | 214 | 360 | 324 | 380 | 516 | 412 | 108 | 34 |
| Gastropod | | | | | | | | | 1242 | 1242 | 68 | 84 | 108 | 128 | 44 | 24 | 56 | 40 | 10 |
| Polychaete Larva | 2 | | | | 1 | 1 | | | 482 | 482 | 44 | 15 | 19 | 9 | 21 | 13 | 24 | 15 | 13 |
| Crustacean nauplius | 8 | | | 1 | | 4 | 3 | | 443 | 443 | 48 | 44 | 40 | 28 | | 20 | 24 | | 9 |
| Zoëa | 42 | 2 | 16 | 2 | | 4 | 16 | 2 | 76 | 76 | 1 | 3 | 1 | 4 | 8 | 12 | 10 | 7 | 1 |
| Decapod Larva | 14 | 3 | 2 | 2 | 2 | 2 | 1 | 2 | | | | | | | | | | | |
| Shrimp larva | | | | | | | | | 66 | 66 | | 1 | 2 | 4 | 6 | 4 | 7 | 19 | |
| Fish Larva | | | | | | | | | 37 | 37 | | 2 | 2 | 3 | 2 | 3 | 1 | | |
| Cladoceran | | | | | | | | | 150 | 150 | | | | 4 | 9 | 18 | 6 | 12 | |
| Sea star | | | | | | | | | 103 | 103 | | | | 12 | 8 | 15 | 25 | 27 | 1 |
| Appendicularia | | | | | | | | | 68 | 68 | | | | | 4 | | | 4 | 4 |
| Cumacean | 8 | 4 | 3 | 1 | | | | | 4 | 4 | | | | | | 1 | | | |
| Echinoderm larva | | | | | | | | | 143 | 143 | | | | | 17 | 36 | 15 | 19 | 8 |
| Decapod | | | | | | | | | | | | | | | | | | | |
| Egg | | | | | | | | | | | | | | | | | | | |
| Ostracod | | | | | | | | | 8 | 8 | 4 | | | | | | | | |
| Amphipod | 1 | | 1 | | | | | | 4 | 4 | | | | | 4 | | | | |
| Foram | | | | | | | | | 317 | 317 | 7 | 24 | 40 | 32 | 16 | 20 | | 4 | |
| Crustacean Larva | | | | | | | | | | | | | | | | | | | |
| Noctiluca | | | | | | | | | 1 | 1 | | | | 1 | | | | | |
| Crustacean | 1 | | | | 1 | | | | | | | | | | | | | | |
| Worm | | | | | | | | | 21 | 21 | 4 | 2 | | 4 | | | | | |
| Hydrozoa | | | | | | | | | 2 | 2 | 1 | | 1 | | | | | | |
| Unidentified larva | | | | | | | | | 27 | 27 | | | 8 | 11 | 1 | 4 | | | |
| Grand Total | 1830 | 331 | 419 | 302 | 188 | 345 | 219 | 26 | 69226 | 69226 | 4852 | 3806 | 4380 | 4844 | 2520 | 4094 | 6988 | 4523 | 807 |

| Row Labels | APS_20110502_12 | APS_20110502_13 | APS_20110503_1 | APS_20110503_2 | APS_20110503_3 | APS_20110503_4 | APS_20110503_5 | APS_20110503_6 | APS_20110503_7 | APS_20110503_8 | APS_20110503_9 | APS_20110504/05_07 | APS_20110504/05_08 | APS_20110504/05_09 | APS_20110504/05_10 | APS_20110504/05_11 | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Filtered volume [m3] | 0.91 | 0.46 | 0.90 | 0.84 | 0.87 | 0.88 | 0.88 | 0.88 | 0.88 | 1.06 | 1.28 | 0.27 | 1.29 | 1.22 | 1.25 | 1.24 | 46.53 |
| Copepod | | | | | | | | | | | | | | | | | 3 |
| Calanoid | 57 | 40 | 1022 | 1260 | 1456 | 1224 | 1096 | 1552 | 212 | 348 | 63 | 268 | 508 | 492 | 836 | 652 | 25630 |
| Harpacticoid | | | 2 | | 6 | 1 | | 4 | | | | | | | 4 | 3 | 47 |
| Cyclopoid | | | | | | | | | | | | | | | | | 1 |
| Nauplius | 222 | 88 | 1610 | 1340 | 1804 | 2272 | 1736 | 1688 | 276 | 246 | 81 | 588 | 896 | 732 | 868 | 988 | 35935 |
| Cypris | 12 | 8 | 130 | 120 | 240 | 288 | 148 | 84 | 32 | 46 | 13 | 16 | 48 | 36 | 88 | 116 | 3445 |
| Bivalve Larva | 24 | 18 | 66 | 232 | 524 | 380 | 292 | 220 | 4 | 70 | 30 | 148 | 120 | 124 | 252 | 232 | 5112 |
| Gastropod | 7 | 4 | 42 | 100 | | 128 | 128 | 108 | 28 | 16 | 7 | 24 | 12 | 12 | 36 | 28 | 1242 |
| Polychaete Larva | 6 | 12 | 16 | 13 | 16 | 11 | 26 | 43 | 12 | 12 | 10 | 32 | 15 | 17 | 27 | 41 | 488 |
| Crustacean nauplius | 8 | 2 | 18 | 24 | 8 | 24 | | 24 | 12 | 8 | 4 | 32 | 24 | 6 | 16 | 20 | 451 |
| Zoëa | | | 2 | 1 | 6 | 5 | 4 | 3 | | 2 | | | | | 1 | 5 | 119 |
| Decapod Larva | | | | | | | | | | | | | | | | | 20 |
| Shrimp larva | | | | | 7 | 5 | 2 | 5 | 1 | 1 | | | | | 1 | 1 | 66 |
| Fish Larva | | | 4 | 1 | 16 | | | | | | | | 1 | | 1 | 1 | 38 |
| Cladoceran | | | 1 | 1 | 2 | 2 | 4 | 3 | | 1 | | 1 | 12 | 14 | 32 | 28 | 150 |
| Sea star | | | | 1 | 4 | 5 | 1 | 2 | 0 | | | 1 | | | | 1 | 103 |
| Appendicularia | | 1 | 2 | | 3 | 1 | | 2 | 1 | 2 | | 4 | 2 | 4 | 16 | 18 | 68 |
| Cumacean | | | | | | | | 1 | | | | | | 2 | | | 13 |
| Echinoderm larva | | | 2 | | | | 2 | | 5 | | | 2 | 4 | | 6 | 27 | 143 |
| Decapod | | | | | | | | | | | | | | | | | 3 |
| Egg | | | | | | | | | | | | | | | | | 3 |
| Ostracod | | | | | 1 | | 2 | | | | | 1 | | | | | 8 |
| Amphipod | | | | | | | | | | | | | | | | | 6 |
| Foram | 2 | 1 | 18 | 44 | 16 | 20 | 12 | 16 | 16 | 2 | 1 | 4 | 4 | 2 | 8 | 8 | 317 |
| Crustacean Larva | | | | | | | | | | | | | | | | | 1 |
| Noctiluca | | | | | | | | | | | | | | | | | 1 |
| Crustacean | | | | | | | | | | | | | | | | | 2 |
| Worm | | | 2 | 1 | 1 | 1 | 3 | | | | | 1 | | | 2 | | 21 |
| Hydrozoa | | | | | | | | | | | | | | | | | 2 |
| Unidentified larva | | | | | | | | | 1 | | | 2 | | | | | 27 |
| Grand Total | 338 | 174 | 2937 | 3138 | 4110 | 4367 | 3456 | 3755 | 600 | 754 | 209 | 1124 | 1646 | 1441 | 2194 | 2169 | 73465 |