Fisheries Research 148 (2013) 64–73

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

DeepVision in-trawl imaging: Sampling the water column in four dimensions

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ARTICLE INFO

Article history:
Received 15 March 2013
Received in revised form 9 July 2013
Accepted 14 August 2013

Keywords:
Trawl camera
Trawl sampling
Fish distribution
Patchiness
Species verification

ABSTRACT

An in-trawl stereo camera system (DeepVision) collected continuous, overlapping, images of organisms ranging from krill and jellyfish to large teleost fishes, including saithe (*Pollachius virens*) and Atlantic cod (*Gadus morhua*) infected with parasitic copepods. The four-dimensional position (latitude, longitude, depth, time) of individuals was recorded as they passed the camera, providing a level of within-haul spatial resolution not available with standard trawl sampling. Most species were patchily distributed, both vertically and horizontally, and occasionally individuals were observed at significant vertical and horizontal separation from conspecifics. Acoustically visible layers extending off the continental rise at 250 m depth and greater were verified as primarily blue whiting (*Micromesistius poutassou*), but also included a small proportion of evenly distributed golden redfish (*Sebastes marinus*) and greater Argentines (*Argentina silus*). Small, but statistically significant, differences in length by depth were observed for blue whiting within a single haul. These results demonstrate the technology can greatly increase the amount and detail of information collected with little additional sampling effort.

1. Introduction

Scantrol AS and the Institute of Marine Research, Bergen, Norway have developed an in-trawl stereo camera system, DeepVision, which images passing organisms before they enter the codend. Here we present results from the first standard survey where the equipment was deployed. Our goal in this paper is not to provide a comprehensive description and interpretation of the ecological relationships and processes in the area, but to demonstrate a sample of information that the technique yields and the types of investigations it could inform. We have chosen to present results from each station in a different way in order to demonstrate multiple examples of how the data can be interpreted and visualized.

The primary gain achieved by using the DeepVision system is enhanced temporal and spatial resolution from trawl data. The precise time, depth, and geographic location is recorded for each individual as it passes the cameras. If organisms maintain their pre-catch distributions, fine-scale information on patchiness and species overlap is preserved. This could be a particular advantage when using a pelagic trawl to verify the identity of organisms in layers or patches detected acoustically. In traditional trawl sampling, catch becomes mixed in the codend and information on where specific species and sizes were encountered within the trawl's path is lost (Kracker, 1999) making it difficult or impossible to tie specific components of the trawl catch to corresponding acoustic registrations.

Multisampler systems which divide catch across multiple codends (Skeide et al., 1997) can provide some information on within-haul distribution, but take a limited number of discrete, temporally sequential samples. The continuous image record saved by the DeepVision system can be analyzed over time intervals on the order of seconds and meter-scale depth intervals. It is even possible to combine time and depth information to, for example, examine differences in the organisms encountered at different phases of trawling (shooting, towing, heaving). By integrating information from other sensors, patterns in distribution in relation to oceanographic conditions can be explored, potentially at much smaller spatial scales than is presently possible (Su et al., 2004).

Another benefit of using the system is reduced size and species selectivity. All organisms that are large enough to be seen in the images are recorded, including ones that are too small to be retained

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http://dx.doi.org/10.1016/j.fishres.2013.08.002

in the codend or gelatinous species that may disintegrate due to abrasion inside the codend (Hamner et al., 1975). We expect that additional uses for this method will emerge, particularly related to improved understanding of ecosystem processes, as the technology and techniques become integrated into trawl sampling for ecosystem based research.

2. Materials and methods

Data were collected onboard the Norwegian research vessel "G.O. Sars" during the annual coordinated ecosystem survey (IESSNS) in the Norwegian Sea and surrounding waters between 2 and 10 July, 2012. This is a combined acoustic and pelagic trawl survey aimed at studying abundance, spatial and temporal distribution, and feeding ecology of small pelagic species and associated prey and predator species. The primary pelagic fish species encountered on the survey are Atlantic mackerel (*Scomber scombrus*), Atlantic herring (*Clupea harengus*), and blue whiting (*Micromesistius poutassou*).

DeepVision equipment was deployed at five locations in the Norwegian Sea. Two hauls were conducted in relatively shallow water on the continental shelf (<350 m depth) and two were conducted at the continental slope, with the trawl fished just above the seabed and across the slope from 325 to 150 m depth. A twist in the trawl at the only station conduced over the continental rise resulted in all catch being imaged when the trawl was on the surface during heaving and the haul was not analyzed further.

We did not use DeepVision equipment at the standard survey stations due to concerns about affecting the performance of the trawl and its catching efficiency. In addition, the sampling protocol for the survey specifies that trawling be done at the surface by attaching large air-filled floats attached to the upper wings and the headline. Since we were interested in using the system to identify acoustic registrations throughout the water column, the floats were removed when the DeepVision was used and the trawl was fished so that it transcribed an oblique tow path sampling from the surface to maximum 350 m depth and back to the surface. The trawling warps were paid out and in slowly during shooting and heaving so that the trawl descended and ascended at a rate of just 0.06–0.08 m s^{-1} while the vessel traveled at a speed of 1.9–2.2 m s^{-1}. Paying out and in slowly also ensured that the trawl maintained similar geometry during shooting, towing at depth, and heaving. The geometry of the trawl did, however, likely vary significantly when the trawl doors were on the surface or onboard the vessel at the very beginning and ending phases of shooting and heaving.

The trawl used is a "Multpelt 832" design, and had an opening of approximately 25 m high by 60 m wide during trawling (ICES, 2012). Mesh size ranged from 16 m in the wings and forward section to 80 mm in the extension where the DeepVision camera system was mounted inside its own 13.4 m long four-panel trawl section (200 m aft of the headrope, stretched length). The section was constructed of 40 mm knotless square mesh and attached to the trawl using a "quick release" method so that the camera could be easily installed and removed from the trawl. The codend (lined with 20 mm knotted diamond mesh) was left attached to the DeepVision section so that only a single seam had to be detached and re-sewn when switching between trawling with and without the camera. Installing or removing the section containing the DeepVision took less than 30 min.

A 90 cm high × 90 cm wide × 150 cm long rigid camera chamber was inserted 8.7 m into the removable trawl section. The camera chamber was constructed of 1 cm thick opaque HDPE, painted yellow in the region visible in the images in order to maximize contrast at the edges of passing organisms and white in the non-visible regions maximize light reflection. The chamber was brought to neutral buoyancy by adding trawl floats (3 mm × 200 mm diameter and 5 mm × 280 mm diameter).

Beginning 2 m ahead of the chamber, panels of 5 mm knotless mesh were sewn inside of the extension in order to guide all catch in front of the cameras. The leading end of this small mesh "funnel" was 90 cm high × 90 cm. The trailing end was attached to a trapezoid-shaped passage inside the chamber which guided all passing organisms through a region entirely within the field of view of the cameras at a range 27–73 cm. The passage was constructed of 1 cm thick transparent polycarbonate and ran the entire 150 cm length of the chamber. It had a cross-section of 1929 cm^2 and the volume imaged by each camera was approximately 150,000 cm^3. The camera chamber and portions of the trawl extension immediately forward and aft are illustrated in Fig. 1.

Five stereo sets of 1392 × 1040 pixels color images were collected per second. The cameras were positioned parallel to one another, with a baseline distance of 60 mm. Lighting was provided by light emitting diode (LED) strobes generating a total of 38,400 lumens of light. The strobes were timed to fire only when the cameras were collecting images. In order to avoid directly lighting the fish and over-exposing light-colored highlights the strobes were oriented so that light was reflected off the roof or floor of the chamber before entering fish passage. Little external light entered from the ends of the chamber in comparison with the quantity generated by the strobes, consequently lighting and image quality remained constant irrespective of the system's depth.

The system operated in an autonomous mode, with no connection to the vessel during deployment. Power was provided by a battery capable of running the cameras and lights for 8 h on a single charge. Image and depth collection was started before the trawl was set out and stopped once it was back onboard, thus a full record was collected for the entire time the trawl was in the water (shooting, towing, and heaving phases). Images were saved to a hard disk inside the subsea housing and downloaded following each haul.

Species identification and counts were done manually based upon reviewing the images. Most fish were imaged multiple times as they passed through the camera's field of view, and were tracked in order to prevent double counting from sequential images. Any fish that re-entered the field of view from the direction of the codend were tracked as well so that they were not counted multiple times. When catches are small and individuals pass the camera singly, a single haul can be processed in approximately equal time to the duration of sampling (e.g. a one hour tow can be analyzed in 1 h). If catches are large, include species that are hard to tell apart, or fish pass the cameras in groups the ratio of analysis time to data collection can exceed 10:1. Individual lengths were calculated by analyzing the stereo image pairs using photogrammetric techniques described in Rosen et al. (2013), similar to those described in Williams et al. (2010). Once the image pairs that are to be analyzed have been selected out of the entire image record, it takes less than five seconds to measure each fish.

Timestamp was used to match the images with vessel position, echograms from the vessel's echosounder (Simrad EK 60, 38 kHz), and trawl geometry measured by Scanmar depth, distance, and trawleye sensors (Scanmar AS, Åsgårdstrand, Norway). The distance between the trawl and vessel was calculated as the long leg of a right-angled triangle with hypotenuse equal to the length of towing warp (logged every second) plus sweeps and the vertical leg equal to depth of the trawl. Trawling was conducted with a constant heading, so the trawl is assumed to have followed in the track of the vessel. The time delay between vessel passage and when the trawl reached the same location was calculated every second as the distance to the trawl divided by the vessel's speed over ground plus the rate at which trawl warp was paid in and out (positive when paying out warp, negative when paying in).