Larval herring, copepod and CTD measure, sampling and analyses

Herring larvae were sampled at nine stations with depths ranging from three to ten meters (Fig. 1) from May to August during the calendar weeks (cw) 18–32. Samples were taken with a Hensen larval-fish net (mouth opening d = 80 cm, mesh size 500 µm and in the codend 300 µm) from near surface (0–1 m) by 10-minute horizontal tows at a speed of 2 knots (see also Ojaveer *et al*. 2011 for further details). The collected larvae were preserved in a 4 % formaldehyde seawater solution.

Zooplankton samples were collected with a Juday net (mouth opening 0.1 m^2, mesh size 100 µm) integrating the whole water column vertically by lifting the net from the bottom to the surface. Samples were preserved in a 4% formaldehyde solution and analysed by the routine method recommended by the Baltic Monitoring Programme (HELCOM 2017). Adults and copepodite stages of copepods were identified to species level. Nauplii were enumerated as a separate group but not identified to species. The major prey of herring larvae (i.e., copepods) was identified and enumerated by considering two developmental stages: nauplii and total copepods.

At the three station (Fig. 1, red crosses), before ichthyoplankton sampling, a CTD cast was made to determine the temperature (°C), salinity, dissolved oxygen (oxygen; mg L^{-1}), and chlorophyll-a (mg L^{-1}, indexed by fluorescence (chlorophyll)). CTD casts were made from the surface to near-bottom for station depths around 5 m. Measurements of each variable were obtained at 1 m depth intervals throughout the water column. The average of these values was used to compute a station mean water-column (MWC) metric for each variable during each cruise.

Image processing and larval measurement

Herring larvae were identified and counted in the samples. Shrinkage due to preservation in formalin was not considered. Notochord length was measured using ZooScan software by LAS (Leica Application Suite) version 4.1 from the images of a maximum of 200 individuals in each sample. Each larvae was measured in three replicates to the nearest 0.1 mm standard length (SL). The length of measured individuals ranged from 5.5–20.0 mm SL. Herring larvae were aggregated according to life stage into four developmental stages (yolk-sac stage: 5.5–8.0 mm, pre-flexion stage: 8.1–10.0 mm, flexion stage: 10.1–17.0 mm and post-flexion stage: 17.1–20.0 mm) based on the protocol recommended by the Ichthyoplankton Information System (http://access.afsc.noaa.gov/ichthyo/StageDefPage. php). Two major distinct life history stages are: yolk-sac stage to characterize number of hatched individuals and postflexion stage to characterize herring larvae that survived the critical first-feeding stage and may have acquired higher likelihood to survive to the recruitment stage (age 1) of the Gulf of Riga Spring spawning herring.

Identification of growth cohorts and calculation of herring larvae growth rate

Larval fish cohorts were identified using the software package "mixdist" (Macdonald 2010) function "mix" in software R (R Development Core Team, 2012) to extract overlapping cohorts and their daily mean lengths. "Mix" analyzes histograms as a mixture of statistical distributions, by finding a set of overlapping component distributions that gives the best fit to the histograms, using grouped-data maximum likelihood.

To calculate mean growth rate (G, mm day^{-1}) by discrete cohorts, the difference between the standard lengths at the largest modes (*L*) in the consecutive surveys was divided by the number of days between the sampling dates (*N*):

$$(G) = \frac{L_E - L_B}{N} \quad (1)$$

where the subscripts *B* and *E* refer to the beginning and the end of the period, respectively (Oeberst *et al*. 2009a). Growth rate was calculated when a cohort could be followed for at least six consecutive weeks (Hakala *et al*. 2003).

Larval herring indices N10, N15 and N20

The estimation of stock indices N10, N15 and N20 requires estimates of mean daily growth (MDG) in relation to T_w (Oeberst *et al*. 2009b). The relation between MDG and T_w was estimated based on the increase of modal valued of the SL of clearly identifiable cohorts in subsequent weeks following the method described in Oeberst *et al.* (2009a). The mean daily growth (MDG) from larval herring standard length (SL), which was applied in larval index calculation process, was estimated from the linear relationship between weekly mean water temperatures at the beginning of the week. The mean daily growth of the larvae (MDG, mm d^{-1}) was estimated from a linear regression on surface temperature (T_w in ˚C; Oeberst *et al.* 2009a) as follows:

$$MDG = f(Tw, \beta) \quad (2)$$

The N20 larval herring index is calculated every year based on data obtained from the larvae survey in Pärnu Bay (GoR). N20 represents a summation of all the larvae that reach a body length of 20 mm over the entire survey period. The length of 20 mm was chosen to minimize the effects of variable mortality during the transition from the yolk-sac stage to the active-feeding stage and of gear

avoidance by large larvae because of their increased swimming speed. For each week the mean growth of larvae was determined until the start of the next weekly survey based on the mean daily growth as function of the water temperature and the number of days between the subsequent weekly cruises. The abundance of larvae of length classes which will be larger than 20 mm at the beginning of next cruise presents the contribution of N20 from the analyses cruise. If exemplarily assumed that mean growth until next cruise is 2 mm follows than larvae of length classes 19 mm and 20 mm present the contribution of N20 of analyses cruise. The sum of the contributions of all cruises presents the total index. Mortality of larvae between subsequent cruises was not taken into account.

The number of larvae of cruise j contributing to the N20 index was defined as the number of larvae ($C_{j,k}$) that reach a length of >21 mm by the first day of the next survey j + 1, using the average T_w data. The contribution of the last survey was estimated differently because information about subsequent development is missing. In this case, all larvae ≤20 mm contributed to the index. The N20 index was calculated as:

$$N20 = A \sum_{j=1}^{n} \sum_{k=k(j)}^{20} C_{j,k} \qquad (3)$$

where n denotes the number of annual surveys, and k_j the minimum length of herring larvae during cruise j which was incorporated into the index of cruise k dependent on the mean surface temperature (Oeberst *et a*l. 2009a).

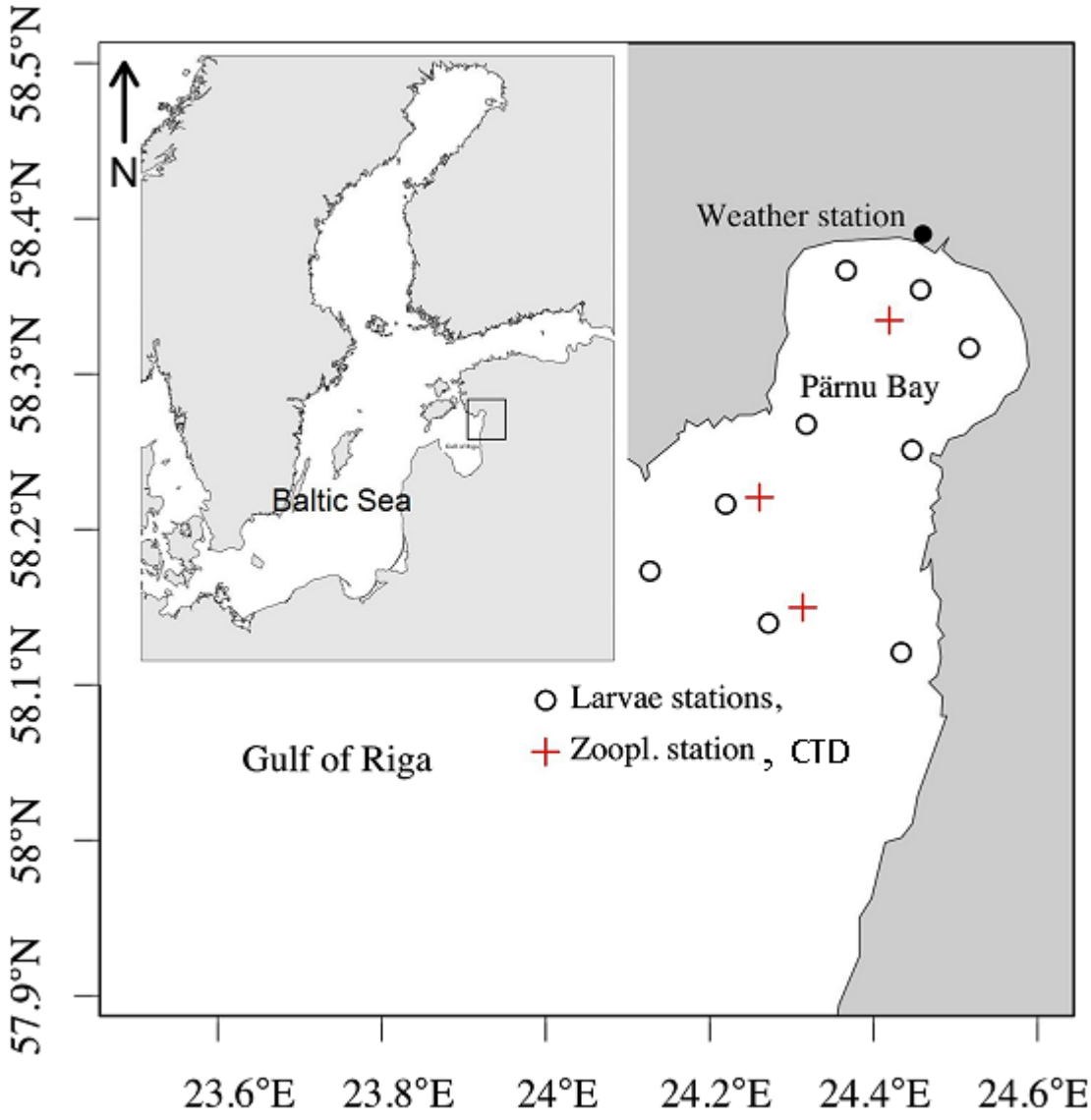

Figure 1. Location of larval herring, copepods, CTD stations in the NE of the Gulf of Riga.

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