

**ABUNDANCE AND DISTRIBUTION OF LARVAL HERRING, *CLUPEA HARENGUS*
(ACTINOPTERYGII: CLUPEIFORMES: CLUPEIDAE) IN THE POMERANIAN BAY,
BALTIC SEA AS AN INDICATOR OF SPAWNING SITES**

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Background. The Pomeranian Bay is one of the most important spawning areas of herring, *Clupea harengus* Linnaeus, 1758, at the Polish coast. The distribution of spawning grounds in the region has only been discussed in one paper, published two decades ago. The identification of the exact locations of the spawning grounds in the bay is of key importance, among others for the evaluation of possible consequences of construction projects in coastal areas, such as that of the gas terminal in Świnoujście.

Materials and methods. Herring larvae (6–29.1 mm standard length, SL) were collected between March and July at six (1992–1996, 1998) and 10 (2007–2011) stations located in the Pomeranian Bay, Baltic Sea, by means of BONGO-nets with 505 µm mesh. The abundance of herring larvae at each of the stations (related to 100 m³) was measured for specimens smaller than 10 mm SL. Such abundances were used as indicators of spawning site locations.

Results. The presence of spring-spawned herring larvae <10 mm in the Pomeranian Bay was recorded from mid-April to the end of June, with the highest numbers from late April to early June. The maximum abundance observed on single day varied from 50 to 667 ind. per 100 m³ in the years 1992–1998, except one day in 1993, when the values reached 2239 ind. per 100 m³ and from 54 to 482 ind. per 100 m³ in 2007–2011. Spawning grounds were identified throughout the study area. In the period of 1992–1998, more intense spawning was observed in the western part of the Pomeranian Bay than in its eastern part. Results regarding the potential impact of the gas terminal construction site provided no indication of its effect on herring spawning intensity and success in the area.

Conclusion. The entire study area in the Pomeranian Bay serves as a spawning ground for spring-spawning herring. Higher intensity of spawning in western part of the bay in the years 1992–1998 was probably a result of more intensive spawning migrations to the Greifswalder Bodden. No effect of the gas terminal construction in Świnoujście (2010 and 2011) on herring spawning or survival of eggs and yolk-sac larvae was observed.

Keywords: fish larvae, spring spawning herring, early life history, spawning grounds, anthropogenic effects

INTRODUCTION

Herring, *Clupea harengus* Linnaeus, 1758, is one of the most important fish species in the Baltic Sea ecosystem. In the Polish part of the Baltic, it spawns along the entire Polish coast, predominantly in the Gdańsk and Pomeranian bays, and in the Vistula Lagoon (Popiel 1955, Strzyżewska 1969, Fey 2001, Krasovskaya 2002). Baltic herring predominantly occurs in two forms depending on the spawning period. These are spring-spawning and fall-spawning herring (Parmanne et al. 1994). Although

spawning in the Pomeranian Bay occurs particularly in spring, some autumn spawning is noted in the area as well. For assessment purposes, a spatial stock separation based on ICES subdivisions (SD) is implemented. Five stocks are distinguished in the Baltic Sea (Anonymous 2012). Variable mixing of stocks is frequent due to migrations, for example between the spawning and feeding grounds. In the southern Baltic, two stocks are present: western Baltic spring-spawning herring (WBSSH; ICES Division IIIa and SDs 22–24), and central Baltic herring (CBH;

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SDs 25–29, SD 32 excluding the Gulf of Riga, SD 28.1). Although the Pomeranian Bay is located in SD 24, and the majority of herring spawning here belongs to WBSSH, considerable mixing with CBH occurs in the area (Podolska and Horbowy 2003, Podolska et al. 2006, Gröhsler et al. 2013). Herring catches take place in the Pomeranian Bay during the migrations of the fish from open waters to coastal spawning areas (Popiel 1955, Strzyżewska, 1969, Krasovskaya 2002, Jørgensen et al. 2005). Herring lays adhesive eggs on submerged substrates such as macrophytes, rocks, and various types of hard bottom surfaces in shallow littoral zones. After spawning in February and March until the end of June (Krasovskaya 2002, Rajasilta et al. 2006), the fish migrate out of coastal areas to their feeding grounds (Garbacik-Wesołowska and Boberski 2000).

An important step in assessing the value of a given geographical area as a spawning site is the analysis of the exact locations of spawning grounds, and possible variability of their distribution over time. Although the Pomeranian Bay is considered an important spawning area on the Polish coast, little information is available regarding the exact spawning ground distribution and larval herring ecology in this region. Porębski (1984) and Porębski and Kaczewiak (1993) described the occurrence of herring larvae in the coastal area of the Pomeranian Bay. No publications provide similar information for the last two decades. The only available data on the ecology of the early life stages of herring in Polish coastal areas published quite recently refer to the Vistula Lagoon (Fey 1999, 2001, 2006). The situation is opposite in the case of information on early life stages of herring available for the western Baltic Sea in the German waters, reviewed recently by von Dorrien et al. (2013).

The basin of the Pomeranian Bay is a coastal area where marine (Baltic Sea) and fresh waters (Odra River) mix, resulting in high dynamics of changes in the biotope. Despite the high variability of this environment, it is an advantageous location not only for the spawning of herring, but also for larval growth, as suggested by results obtained by Höök et al. (2008). Based on RNA : DNA analysis of herring larvae, the author concluded that the sheltered coastal waters of the Baltic Sea are high-quality nursery areas for early life stages of herring. Similar conclusions are suggested by the herring larvae distribution and abundance data presented by Urho and Hildén (1990) for coastal waters off Helsinki, Finland.

Despite the generally favourable conditions for larval fish growth and survival in the bay, the location of the spawning grounds in the vicinity of the shore and demersal type of eggs make herring eggs and early larval stages exposed and sensitive to different types of human impacts. In recent years, such potential danger could be related to the construction of the LNG (liquefied natural gas) terminal in Świnoujście. The construction commenced in 2010, and should be completed by the end of 2014. The terminal itself is located on land, but the execution of seagoing structures was also necessary. They were related to works involved in the construction of the external harbour, such

as the repair of the old breakwater (from March 2010 to June 2012), building a new 3-km-long breakwater (April 2010 to May 2013), and building a 256-m-long spur (commenced in July 2011). Over the study period, such activities could have caused substantial sediment spill during the repair of the old and construction of the new breakwater, as well as during the deepening of the external harbour in the spawning seasons 2010 and 2011. Moreover, considerable noise pollution was caused by pile driving in spring 2011 (construction of the new breakwater). The behaviour of adult fish and survival of eggs and larvae could have been significantly affected by both the sediment spill (Westerberg et al. 1996, Engell-Sørensen and Skyt 2001) and noise pollution (Kostyuchenko 1973, Hastings and Popper 2005). In the scope of the presently reported study, such potentially negative consequences for both the adult herring spawning aggregation and the survival of eggs and larvae could be expected in 2010 and 2011 on one of the sampling stations, located approximately 0.5 km from the construction site.

The objective of the study was to determine the distribution of herring spawning sites, and to evaluate possible differences in their geographical pattern in the Pomeranian Bay, based on the abundance of small larvae (<10 mm SL) in two distinct periods: 1992–1998 and 2007–2011. The paper also considers the possible impact of the construction of the external harbour to gas terminal in Świnoujście in 2010 and 2011 on herring spawning.

MATERIALS AND METHODS

Sampling. Larval herring, *Clupea harengus*, 6–29.1 mm (standard length) were collected during 3–6 annual single-day cruises between March and July at 6 (1992–1996, 1998) and 10 (2007–2011) stations located in the Pomeranian Bay, Baltic Sea (Tables 1 and 2, Fig. 1). BONGO-nets with 505- μ m mesh, equipped with flow meters, were used for approximately 10 min in double oblique hauls from the surface to the bottom at a speed of 5–5.6 km \cdot h⁻¹. The samples were preserved in 10% formaldehyde solution buffered with sodium borate. The herring larvae were sorted, counted, and measured (standard length; SL) to the nearest 0.1 mm with electronic callipers.

Data analysis. The abundance of herring larvae at each of the stations ($n \cdot 100 \text{ m}^{-3}$) was estimated for specimens smaller than 10 mm SL. The abundance of the small larvae was adopted as an indicator of spawning sites (the mean size of the larvae used for the distribution analysis was 7.9 mm SL). The selected size range:

- Represented small larvae within a few days from hatch, with a size of approximately 6–9 mm (Urho 1992, Horbowa and Fey 2013);
- Represented larvae predominantly at the yolk-sac stage (Rosenthal and Hempel 1970, Kiørboe et al. 1985, Horbowa and Fey 2013); and
- Provided an adequate sample size for analysis.

In their study off Helsinki coast, Urho and Hildén (1990) similarly grouped herring larvae by size into classes of <10 mm, 10–15 mm, and >15 mm. Temporal

changes in larvae abundance over a year, at all of the stations and in all of the years, were presented on one scatterplot. Because some of the data points represented values much higher than others, the Y axis was log-transformed in order to improve the readability of the graph.

Two most abundant sampling periods (sampling days) in each of the years are presented on maps. They were used for analyses aimed at the identification of the location of the main spawning sites. The locations of the distinct hauls from a given year provide information on the place of spawning during the main spawning period. It should be remembered, however, that the location of a spawning site is not estimated by direct observation of the spawners, but based on the position of particular larval fish hauls. Differences in the geographical distribution of larvae were also compared in a descriptive way after the division of the stations into two groups, namely: Line I (stations located close to the shore at a depth of approximately 4 m) and Line II (stations located farther from shore at a depth of approximately 10 m) (see Table 2 and Fig. 1 for the stations' depth and geographical distribution). For the purposes of the analysis, larval herring abundance at individual stations was recalculated as the percentage of the total number of larvae collected on a given day. Due to this, values for different days and years are comparable despite significant differences in absolute abundance. Larval abundance at each of the stations was presented on a box-whiskers plot (arranged on X axis in order of geographical position from west to east), and compared statistically with nonparametric Pearson's Chi-squared test (Statistica[®]6.1).

The possible effect of the construction of the LNG Terminal on herring spawning and survival of eggs and yolk-sac larvae was verified by comparing the abundance of larvae < 10 mm at station No. 7 (Fig. 1) with their

abundance at other stations on a given day. Station No. 7 is located less than 500 m from the construction site.

RESULTS

The presence of spring-spawned herring larvae <10 mm SL (mean size: 7.9 mm) in the Pomeranian Bay increased from mid-April to the end of June, with the highest values of both the maximum and minimum abundances on a given day in the period between the end of April and the beginning of June (Fig. 2). The occurrence of herring larvae in the period of 1992–1998 reached a clear peak at the end of May, and a smaller one at the end of April. In the period of 2007–2011, no such distinct peak was observed, but two smaller peaks were present, namely at the end of April and in mid-June.

The maximum abundances observed on single day varied from 50 to 667 ind. per 100 m³ in 1992–1998, except one day in 1993, when the values reached 2239 ind. per 100 m³ (Fig. 3) and from 54 to 482 ind. per 100 m³ in 2007–2011 (Fig. 4). The median for the two most abundant days of each year amounted to 28 (mean = 136) ind. per 100 m³ in the years 1992–1998, and 29 (mean = 60) ind. per 100 m³ in the years 2007–2011.

Spawning grounds of spring-spawning herring were indicated by the presence of larvae < 10 mm. They were found throughout the study area of the Pomeranian Bay (Fig. 3 and 4). In the period 1992–1998, more intense spawning was observed in the western part of the Pomeranian Bay than in its eastern part, as suggested by the differences in larval abundance allocated to Line I (stations close to the shore at a depth of approximately 3 m) (Fig. 5A). The differences were statistically significant (Pearson's Chi-squared test, df = 2, $P < 0.05$). No such differences were recorded for Line I in the years 2007–2011 (Fig. 5B) (Pearson's Chi-squared test, df = 4,

Table 1

Summary of the herring larvae (*Clupea harengus*) sampling schedule. Only larvae sized <10 mm SL were used in the analyses of abundance and distribution

Year	N_s	Months	No. of stations	Stations analysed	Standard length of larvae [mm]			
					Sampled		Analysed	
					Mean	Range	Mean	Range
1992	5	Apr–Jun	3–6	6	8.2	6–26	7.3	6–9.9
1993	3	May–Jun	3–6	6	11.3	6–25	8.1	6–9.9
1994	5	Apr–Jun	3–6	4–5	10.3	6–29	8.4	6–9.9
1995	4	Apr–Jun	3–6	6	11.6	6–24	7.7	6–9.9
1996	3	Apr–Jun	3–6	6	10.1	6–25	8.2	6–9.9
1998	6	Apr–Jul	6	6	11.5	6–27	7.1	6–9.9
2007	6	Apr–Jun	9–10	9–10	13.1	6–26	7.4	6–9.9
2008	6	Apr–Jul	8–10	8–10	11.3	6–26	7.9	6–9.9
2009	6	Mar–Apr	7–10	7–8	11.4	6–24	8.5	6–9.9
2010	8	Apr–Jul	8–10	9–10	11.8	6–27	7.0	6–9.9
2011	6	Apr–Jun	4–10	10	12.9	6–25	7.6	6–9.9

N_s = Number of sampling days, Stations analysed = number of stations for the days used in the analyses (i.e., two days from a given year distinguished by the highest larval abundance).

$P > 0.05$). For Line II (stations farther from the shore at a depth of approximately 10 m), the differences in larval abundance between stations were not statistically significant neither for the years 1992–1998 nor 2007–2011 (Figs. 5C i 5D) (Pearson's Chi-squared test, $df = 4$, $P > 0.05$).

Although in 2010 the abundance of herring larvae at station No. 7 (located less than 500 m from the construction area) was relatively low on 13 May, the most abundant day in that year, the difference was not radical, and was not confirmed on 28 May, the next most abundant day in that year (Fig. 4). No reduction in larvae abundance in comparison to the remaining stations was recorded at station No. 7 in 2011.

DISCUSSION

Recruitment success, including that of Baltic herring (Oeberst et al. 2009a, Ojaveer et al. 2011), depends on the number of larvae produced in a given reproductive season that survive to older ages (Houde 2008, Shepherd and Cushing 1980, Heath 1992, Nash et al. 2009). Therefore, three factors are crucial for obtaining good year-classes: the availability of suitable spawning grounds, the occurrence of conditions permitting the spawning of adults, and appropriate conditions supporting the survival of eggs, hatching success, and growth and survival of larvae. The presently reported study considers the first three factors

Table 2

Characteristics of the larval herring (*Clupea harengus*) sampling sites in the Pomeranian Bay

Y	Station	Coordinates		Depth [m]
1992–1998	1	53°55'50"N	14°18'00"E	3
	2	53°54'90"N	14°22'00"E	3
	3	53°56'10"N	14°26'70"E	3
	4	53°57'50"N	14°18'00"E	9
	5	53°56'90"N	14°22'00"E	9
	6	53°57'50"N	14°26'00"E	11
2007–2011	1	53°57'39"N	14°28'21"E	5
	2	53°58'35"N	14°27'97"E	11
	3	53°55'89"N	14°25'98"E	5
	4	53°56'83"N	14°24'50"E	10
	5	53°57'09"N	14°21'95"E	9
	6	53°54'92"N	14°20'24"E	5
	7	53°55'30"N	14°18'58"E	5
	8	53°56'58"N	14°17'72"E	9
	9	53°57'89"N	14°15'68"E	10
	10	53°55'81"N	14°14'38"E	5

Y = year range.

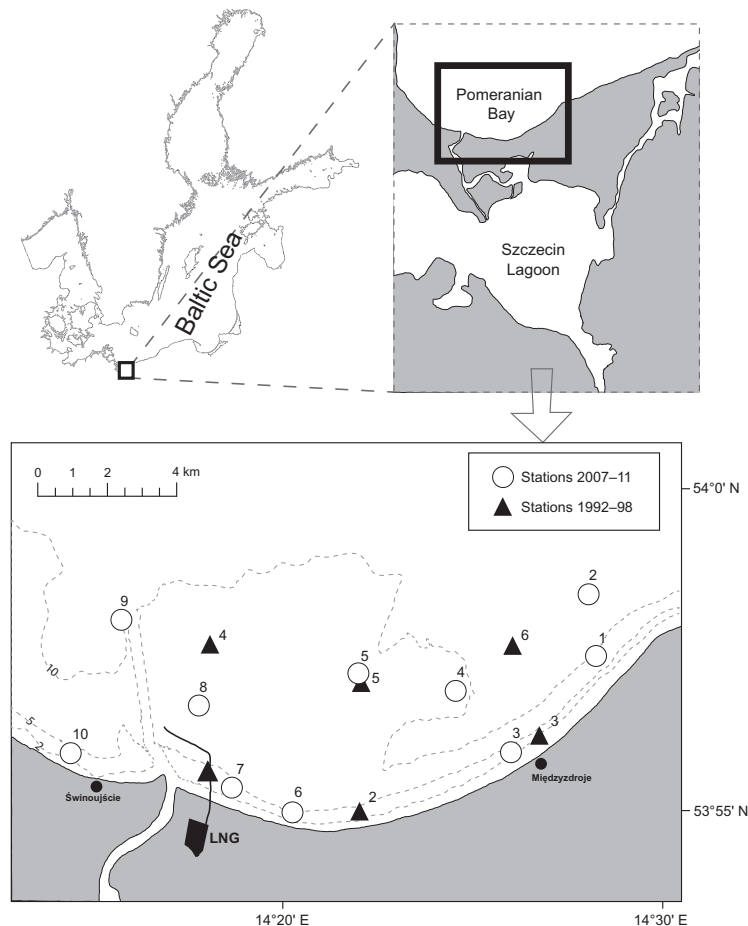


Fig. 1. Map of the study area: numbers denote station numbers, the Liquefied Natural Gas Terminal (LNG) construction site together with the seagoing breakwater (build in 2010–2013) is shown (Map: Lena Szymanek and Paweł Majewski)

for the herring in the Pomeranian Bay by analysing the abundance and distribution of small larvae (< 10 mm SL). Their presence in a given geographical area suggests the occurrence of herring spawning as well as eggs and yolk-sac larvae survival.

With regard to the early life stages of herring in the Pomeranian Bay, Porębski (1984) and Porębski and Kaczewiak (1993) found that concentrations of spring-spawned herring larvae in the area occurred in the coastal belt extending up to 3 NM offshore from Świnoujście to Międzyzdroje from late March to early July 1982. The authors located spawning sites based on the distribution of larval herring with a length of less than 9 mm. This study, conducted from two to three decades following the publication of the above-mentioned two papers, provides the same conclusions, namely: herring spawning occurred in shallow waters with a depth of <5 m along the coast from the Polish–German border (i.e., west of Świnoujście) to several miles east of Międzyzdroje. This region covers the entire area analysed in the study. Because no sampling was done further east, it is not possible to compare the abundance of larvae in the bay to that in the adjacent waters. Unfortunately, no other data for the Pomeranian Bay are available for comparison. Considerably more information is available from the German side of the border, regarding larval and juvenile herring distribution in the nearby Greifswalder Bodden and adjacent waters, including both historic (Thieme and Biester 1981, Brielmann and Biester 1981, Brielmann 1989, Biester 1989) and more recent data (Oeberst et al. 2009a, 2009b, von Dorrien et al. 2013, Polte et al. 2014).

The observed abundances of up to approximately 500–600 ind. per 100 m³ (and exceeding 2000 in 1992), with a median for the two most abundant days within each year = 28 (mean = 136) ind. per 100 m³ in the years 1992–1998, and = 29 (mean = 60) ind. per 100 m³ in the years 2007–2011, confirm that the Pomeranian Bay is an important herring spawning area. In enclosed and shallow (<5 m) water bodies such as the Vistula Lagoon, the abundance of larvae of up to 10 mm may even reach 15–20 000 ind. per 100 m³ (Fey unpublished). In other regions, however, such values are rarely found. In the Greifswalder Bodden, constituting the most important herring spawning area at the German coast, and one of the most important ones in the Southern Baltic, the maximum abundance of larvae up to 9 mm TL reached approximately 1400 ind. per 100 m³ in the majority of years between 1994 and 2011. The median from all of the stations during the peak occurrence amounted to approximately 600 ind. per 100 m³ in the years 1994–1998, and approximately 100 ind. per 100 m³ in the years 2007–2011 (Polte et al. 2014). The abundance of small herring larvae in Greifswalder Bodden appears to be considerably higher than that in the Pomeranian Bay. Even if this to some extent results from the enclosed character of Greifswalder Bodden and the open-area character of the Pomeranian Bay, the differences in larval abundance suggest differences in the importance of those spawning areas. For the years

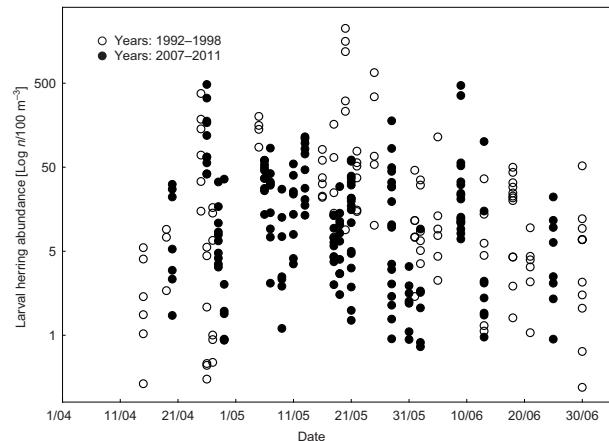


Fig. 2. Abundance of herring larvae (*Clupea harengus*) <10 mm SL at all of the sampling stations in two sampling periods: 1992–96, 1998, $n = 113$ (empty circles) and 2007–11, $n = 196$ (solid circles)

1983–1986, Urho and Hildén (1990) reported the densities of herring larvae in the coastal waters off Helsinki generally below 100 ind. per 100 m³, with maximum values around 300 ind. per 100 m³. It is worth emphasizing, however, that those values were obtained for larger ranges of larval sizes than in the presently reported study, namely predominantly 12–25 mm. The abundance of larvae <10 mm was very low.

More detailed analyses of data collected in the scope of this study, such as the determination of the dependence of the abundance of herring larvae on spawning stock biomass, and the dependence of larval growth rates on zooplankton quantity and temperature, will be provided in a separate publication, currently under preparation.

The intensity of spawning along the coast in the Pomeranian Bay was higher in the western part of the bay in the years 1992–1998. In the years 2007–2011, spawning intensity was found to be relatively evenly distributed. This small but significant change may be related to generally much less intensive herring spawning in the neighbouring Greifswalder Bodden in the years 1994–1998 as compared to the years 2007–2011 (Polte et al. 2014). Spawning intensity in the western part of the Pomeranian Bay must be affected by the magnitude of the spawning migration of herring to the Greifswalder Bodden more than in its eastern part.

The lack of significant changes in the spawning ground distribution in the Pomeranian Bay over such a long period from 1982 (Porębski 1984) to 2011 (presently reported study) is probably related to the absence of environmental changes sufficient to cause changes in spawning in any part of the study area. Currently, such changes could potentially occur as a result of the construction of the Liquefied Natural Gas (LNG) terminal in Świnoujście. The construction commenced in 2010. In the period 2010–2011, covered by the study, it involved the construction of the external harbour, the repair of the old breakwater, and the construction of a new 3-km-long breakwater. All those operations must have been responsi-

ble for substantial sediment suspension and noise pollution (especially during pile driving). Sediment suspension can potentially affect the quality of spawning grounds by scaring the fish, dispersing spawning aggregations (Westerberg et al. 1996, Engell-Sorensen and Skyt 2001), and increasing mortality of demersal eggs and small larvae (Westerberg et al. 1996). A similar effect is expected in the case of noise pollution, from scaring the fish, or in

extreme situations even killing them (Hastings and Popper 2005), to affecting the development and survival of eggs and larvae (Kostyuchenko 1973). One of the study stations (No. 7) was located less than 500 m from the construction site. Although some fluctuations of larvae abundance and distribution are natural, the mass extinction of larvae at station No. 7, particularly during both of the years 2010 and 2011, could be related to the effect of the

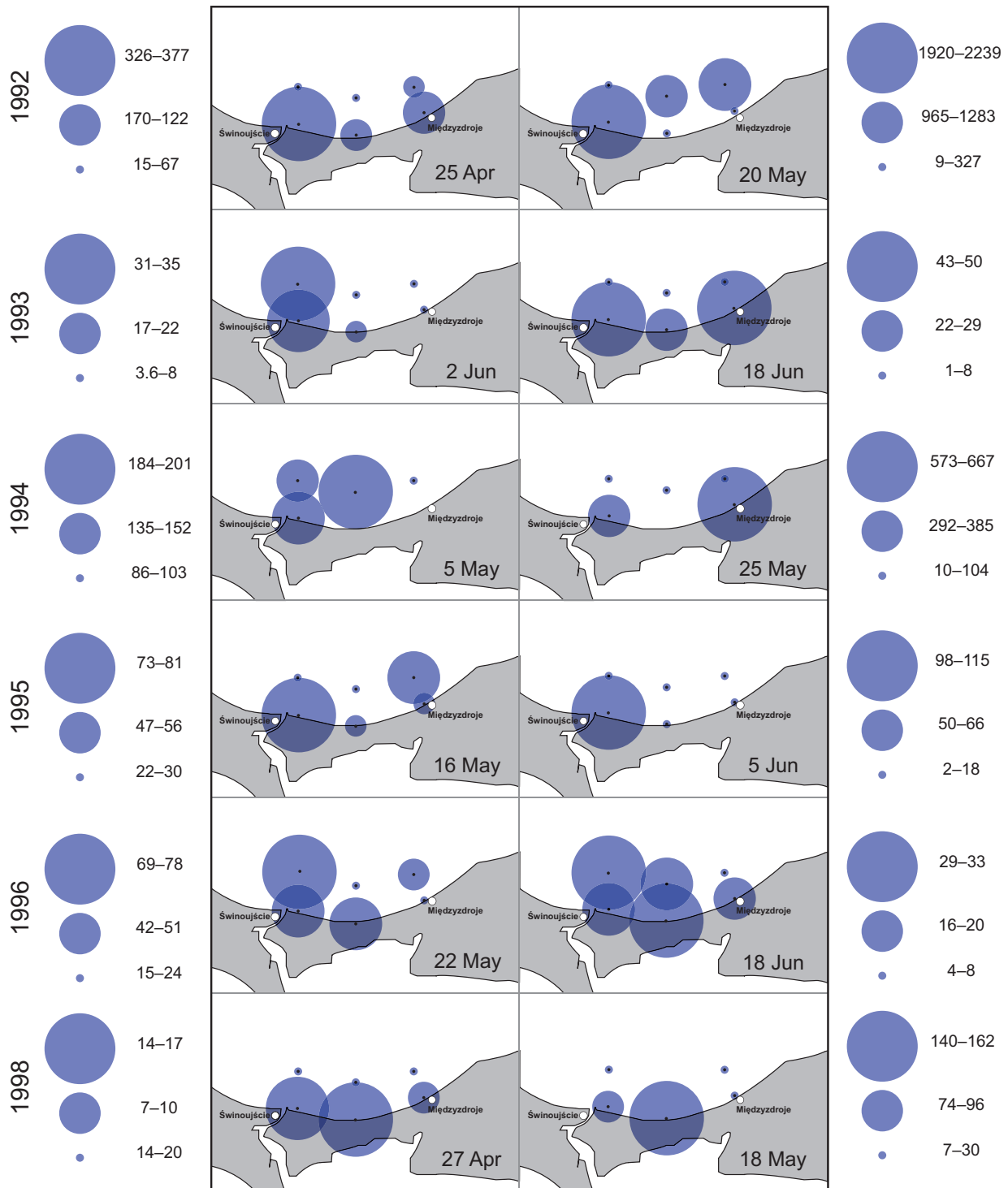


Fig. 3. Distribution and abundance ($n \cdot 100 \text{ m}^{-3}$) of herring larvae (*Clupea harengus*) <10 mm SL for the two most abundant sampling days in each year (1992–1998); For each year, the abundance is grouped in seven categories, three of which are shown in the legends

construction of the terminal. The study results, however, do not permit drawing such unequivocal conclusions. A reduced number of small larvae in the construction area in comparison to other stations was observed in 2010, but its magnitude was too small to clearly connect it to the effect of the terminal. In 2011, the abundance at station No.7 was comparable to that at the remaining stations.

As shown above, the entire coastal area of the Pomeranian Bay provides important spawning grounds for spring-spawning herring, with no distinct areas of higher importance. The construction of the LNG Terminal in Świnoujście in 2010 and 2011 seems to have had no

considerable effect on the herring spawning intensity and survival of its early life stages in the Pomeranian Bay.

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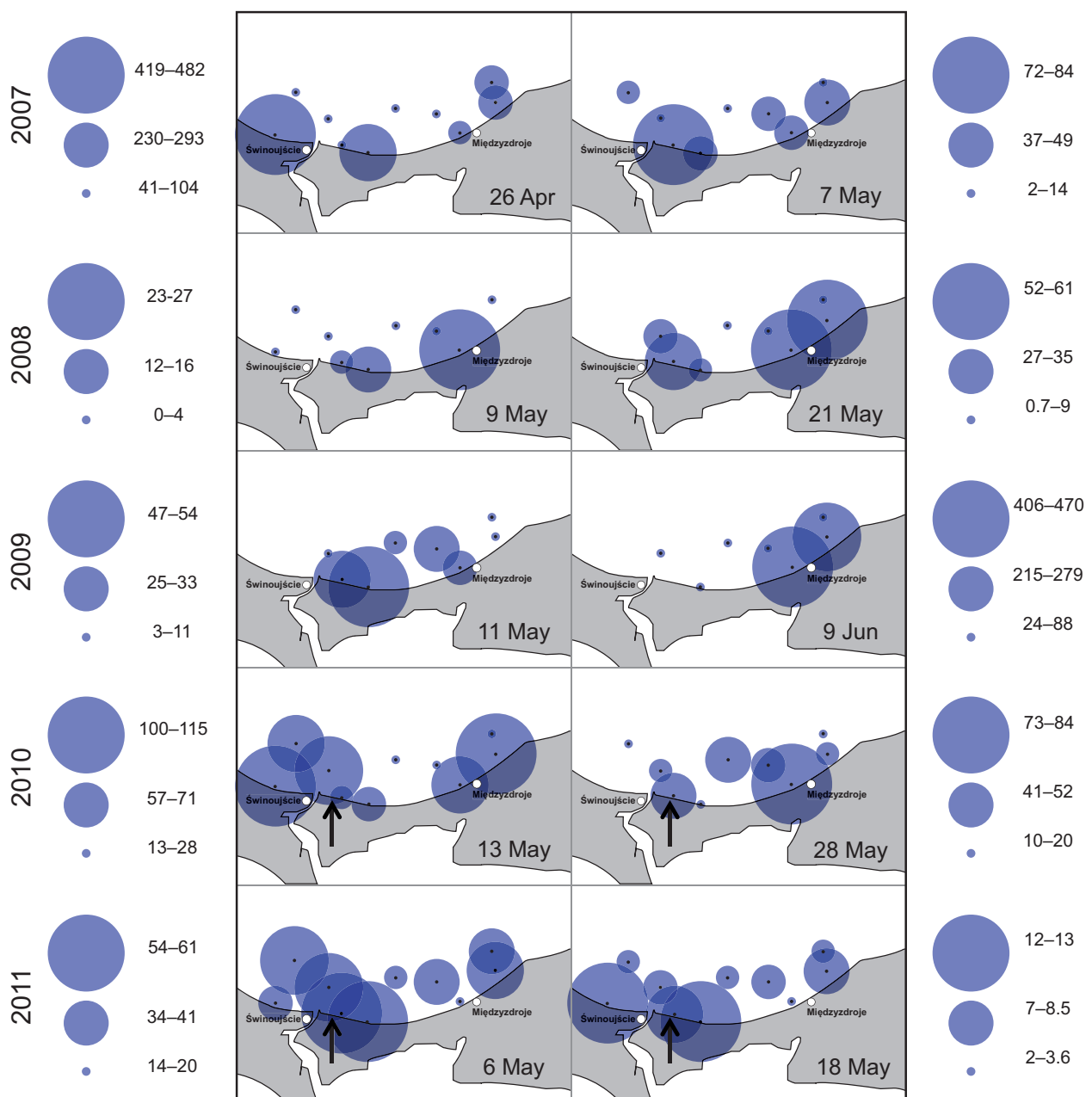


Fig. 4. Distribution and abundance ($n \cdot 100 \text{ m}^{-3}$) of herring larvae (*Clupea harengus*) <10 mm SL for the two most abundant sampling days in each year (2007–2011); For each year, the abundance is grouped in seven categories, three of which are shown in the legends; The arrows show the location of the LNG terminal construction site (intensive works in the area took place in 2010 and 2011)

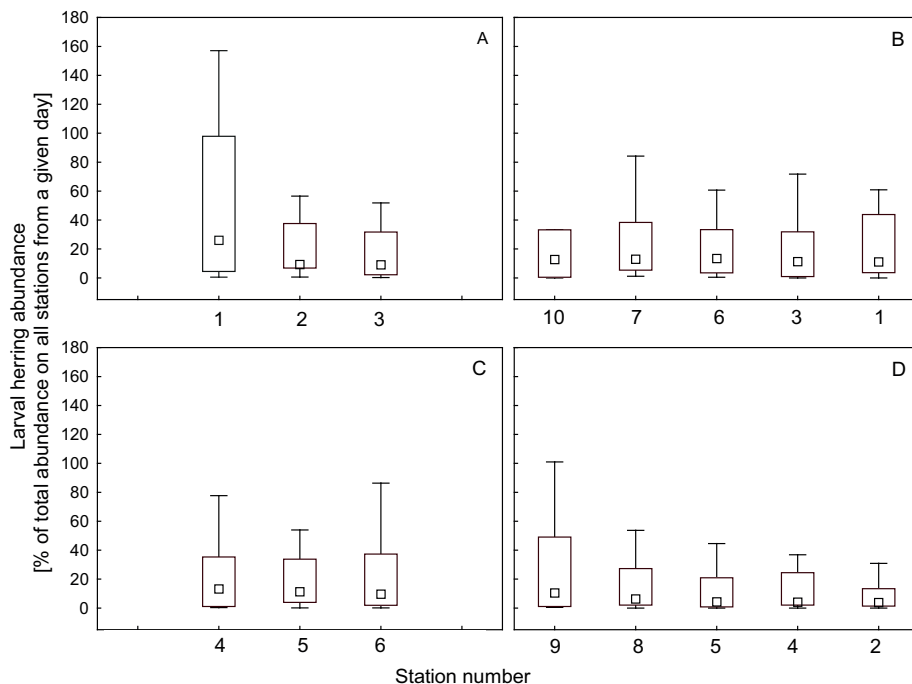


Fig. 5. Abundance of herring larvae (*Clupea harengus*) <10 mm SL for the two most abundant sampling days in each year; **A** years 1992–1998, Line I (close to the shore at a depth of approximately 5 m); **B** years 2007–2011, Line I; **C** years 1992–1998, Line II (farther from the shore at a depth of approximately 10 m); **D** years 2007–2011, Line II; The mid-points represent the median of the abundance at a given station as a percentage of total abundance at all of the stations from a single sampling day; the box represents 25%–75% range, and the whiskers represent not protruding minimum and maximum; Stations are plotted from left to right in order representing geographical position from west (Świnoujście) to east (Międzyzdroje)

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