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Technical Report No. 7

ASSESSMENT OF FISH SPAWNING GROUND EFFICIENCY

Project indicator:
1. Documented assessment of fish spawning ground efficiency

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CONTENT

1. Introduction

Baltic herring, *Clupea harengus membras*, is the dominant fish species in the Baltic Sea (Rajasilta et. al., 2006). This makes it not only an important pelagic resource for commercial fishing (Cardinale & Arrhenius, 2000), but also an important part of the Baltic Sea ecosystem. For proper management, understanding of various aspects of herring biology is needed (Geffen, 2009).

Spawning is one of the most important stages of the fish life cycle, crucial for stocks restoration. Knowledge of Baltic herring spawning grounds in the Lithuanian part of the Baltic Sea was limited and inaccurate. Even less was known about factors that drive spawning grounds distribution. To close this gap a study was performed in 2009-2010. During two seasons, SCUBA divers were collecting data about Baltic herring spawn spawning locations.

High resolution multibeam bathymetry and Side Scan Sonar sediment map were available for part of the potential spawning area, and to find factors which could be responsible for spawning grounds distribution, significant sampling efforts were concentrated in this area during 2010 season.

2. Baltic herring population structure

Baltic Sea is known for its strong environmental gradients. For example, salinity changes from 30-32 psu in Skagerrak to 2-3 psu in Bothnia bay. Those gradients determine correspondent changes in the local ecosystems properties. Atlantic (Baltic) herring is found throughout the Baltic Sea exhibiting considerable morphological (e.g. vertebrae counts) and ecological (e.g. spawning time differences and migration patterns) variations (e.g. Aro 1989; Parmanne et. al., 1994). The genetic structure of populations could be affected by both qualitative and quantitative features (Gabrielsen et. al., 2002). **(**Jørgensen et. al., 2005**).**

The information collected through recent studies reveals a complex population structure of herring, and demonstrates that the high level of adaptability must be a basic trait. Once, the picture was simple; now, with more data available, the picture proves to be more complex. However, despite the obvious need to synthesize the available information for a better understanding, a single unifying explanation for all observed herring patterns is still elusive. (Geffen, 2009).

Baltic herring have a variety of spawning strategies. Individual population components have traditionally been distinguished based on differences in spawning time, and there are temporally stable differentiations among spawning locations along an environmental gradient. Those differences remain stable despite the facts that herring larvae (which are pelagic and may drift several hundred kilometers over a few months (Johannesen & Moksness 1991) and grown individuals migrate freely (Bekkevold et. al., 2005). Even in the same area there could be several populations (such as spring and autumn spawners), which could be distinguished morphologically only by gonads development.

The genetic analysis studies showed, that there is no clearly distinguishable difference between populations occupying different areas of the Baltic (Gulf of Bothnia, Archipelago Sea, Greifswalder Bodden). Instead, the variation between individuals is very high (Rajasilta et. al., 2006). Although some studies employing microsatellite DNA markers have revealed statistically significant albeit low differentiation among spawning groups from open marine areas (e.g. Shaw et. al., 1999; McPherson et. al., 2004), interpretation of those results beyond the general finding that genetic differentiation is present among Baltic Sea herring spawning groups, is complicated **(**Jørgensen et. al., 2005)

There are some indications that salinity conditions strongly modify herring characteristics in general (Rajasilta et. al., 2006), but number and particularities of individually spawning populations within different areas often remain unknown. Some authors suggest that there are fishes of the same maternal lineage spawning at different times in the same area and even in different parts of the Baltic (Rajasilta et. al., 2006).

3. Spawning periods and locations

Herring appear quite unique among marine fish in having a wide range of discrete spawning seasons while using very specific spawning locations. These two aspects represent the major characteristics. The life-history strategy appears so flexible that this species can produce viable eggs at most times of year. This means that the eggs and larvae are adapted to the varied seasonal conditions of temperature, light hydrographic conditions, predator fields, and food availability. (Geffen, 2009).

Baltic herring exhibits a south to north cline in spawning times. The earliest spawning occurs in the southwestern and southern areas and lasts from March to May at a minimum water temperature of 4°C and a salinity of 4 psu (Klinkhardt, 1996). In the northern part of the Hano Bight, spawning takes place during April-May at temperatures of 5.5-15°C (Elmer, 1983). Evtjukhova and Berzinsh (1983) and Kornilovs (1994) reported the highest spawning activity in the Gulf of Riga from late May to early June at water temperatures of 9.5-16.9°C. In the Asko Archipelago, spawning dominates during May-June (Aneer, 1989) at water temperatures of 4-15°C, mid summer at average water temperatures of 6-7°C (Oulasvirta et. al., 1985). In the Bothnian Bay located in the northernmost part of the Baltic Sea, spawning begins one month later and sometimes takes place in July. Thru the different parts of Baltic, major spawning event occurs at water temperatures ranging from 3-4°C to 15-16°C (6-7°C, on average) (Krasovskaya, 2002). It should be noted that even though temperature *decreases* from south to north, the temperatures during spawning time tend to *increase* with latitude, due to a generally later spawning season in northern populations (June) as compared to southern populations (March–May). (Jørgensen et. al., 2005). The salinity on the spawning grounds may vary from about 35 to 5 (Kiel Canal) psu. (Holliday & Blaxeter, 1960). Soft bottom substrates are generally not used for spawning (Rajasilta et. al., 1989, Kääriä et. al., 1997), and usually herring spawn on hard substrates with different bottom vegetation. For example, in Finland coastal waters herring spawns on hard bottom vegetation, on at least 32 different plant species (Aneer, 1989). There are reports, that eggs are attached on the vegetation after visual inspection and after sensing the substratum by the fins (Kääriä, 1999 and references therein). (Bergström et. al., 2007). The spawning depth is area and population specific and can vary from 0.5 to 4 m (Aneer et. al., 1983) to about 8 m depth, or even more, depending on water quality and other environmental conditions. Often spawning sites are close to deep water areas (Kääriä et. al., 1988, Rajasilta et. al., 1993, Kääriä et. al., 1997). The spawning beds can be some square meters or tens of meters wide (Kääriä, 1999), and herring returns to the same spawning grounds year after year (Oulasvirta & Lehtonen 1988) (Bergström et. al., 2007), even if there are strong anthropogenic influence in the area (Rajasilta et. al., 2006). Potentially suitable spawning areas usually much larger than actual spawning grounds (Kääriä et. al., 1997), and reasons for this remain largely unknown.

4. Development of eggs

Salinity effects. Different salinity requires different osmotic regulation. As Baltic herring spawns in areas with significant salinity differences, ability of the eggs to withstand those changes was a subject to a number of experimental studies. As are results reported, that optimal salinity for Baltic herring eggs fertilization is 22.7 psu, and for optimum hatching 20-35 psu (Holliday et. al., 1964). However, eggs and larvae survive in much larger salinity diapason, from 5 to 52.5 psu. During experimental studies some embryos remained inactive but alive (heart beating) after 24 h exposure in 0.35-1.7 psu, with higher tolerance of eggs incubated in lower salinity. No difference was found in oxygen uptake of either eggs or larvae that could be attributed to salinity. However, disturbances in oxygen uptake were apparent for 6-8 h following transfer in different salinity. It is during this time that the larvae experience osmotic imbalance before regulating the changing body fluids (Holliday & Blaxter, 1960; Holliday et. al., 1964). This indicates that rapid salinity changes, occurring in the Lithuanian part of the Baltic Sea due to Curonian Lagoon waters interventions, could have a certain effect on eggs development.

Oxygen requirements. The oxygen requirements of the eggs vary with the stage of embryo development, according to some authors from 1.93 to 3.08 ml/l. The early stages of larvae reported to show some degree of "regulation" of oxygen uptake as the oxygen concentration fell, i.e. they held or nearly held their uptake to that at the air saturation level. Later feeding larval stages showed "conformity", i.e. the oxygen uptake fell with the oxygen concentration of the surrounding water. After metamorphosis and the appearance of respiratory pigment a degree of "regulation" re-appears. (Silva & Tytlerb, 1973).

Temperature effects. Water temperature is an important factor for herring eggs development. For many fish species water temperature is also a "trigger" which induces start of the spawning. Although in the Baltic Sea different herring populations start spawning at different temperature, there is a documented example of abnormally intensive spawning of the herring which, most likely, was triggered by rapid rising of sub-surface water temperature (Messich & Rosenthal, 1989)

The upper optimal temperature for Baltic herring embryos reported to be 12–13°C (Saat & Veersalu, 1996), and severe abnormalities of embryos have been detected at 17°C (Ojaveer, 1981). The lower optimal temperature for Baltic herring embryos is approximately 5°C. During laboratory experiments with eggs incubation in 4 psu salinity and 10°C, hatching started 185 hours after eggs fertilization, and mass hatching after 202-216 hours. (Veersalu & Saat, 2002)

Effect of spawning substrate. Baltic herring in not very substrate specific and laying it eggs on the wide variety of the plants species (Aneer, 1989). However, field surveys and experimental studies indicate that egg mortality can be higher on certain plant substrates, such as *Furcellaria lumbricalis, Phyllophora* (Rajasilta et. al., 1989, 1993, 2006) or *Pilayella littoralis* (Aneer, 1987). Heavy precipitation of organic material, for example diatoms *Skeletonema costatum* (Greville) onto the egg layer also could lead to high (from 7% to 98% within six days) eggs mortality (Morrison et. al., 1991). It should to be noted, that after the embryo has died, the egg is detached from the substrate and easily washed away by waves and water currents (Rajasilta et. al., 2006), and therefore accurate estimation of eggs mortality *in-situ* could be problematic.

5. Materials and methods

5.1 Planning

Based on the reviewed literature and previous knowledge, on the very exposed Lithuanian Baltic Sea coast most suitable substrate for herring spawning was deemed *F. lumbricalis* meadows. Five spawning locations, occasionally detected on *F. lumbricalis* during previous studies, supported this hypothesis. For the 2009 study field season 50 points evenly distributed (average distance between the points approx 800 meters) over the *F. lumbricalis* habitat were chosen for sampling (Fig. 1).

Prior to 2010 field season a high resolution multibeam bathymetry and Side Scan Sonar sediment map became available for the part of the potential spawning grounds area. To determine environmental factors important for herring spawning grounds distribution, second season sampling efforts were concentrated at those areas. 42 points were planned for sampling (Fig. 2).

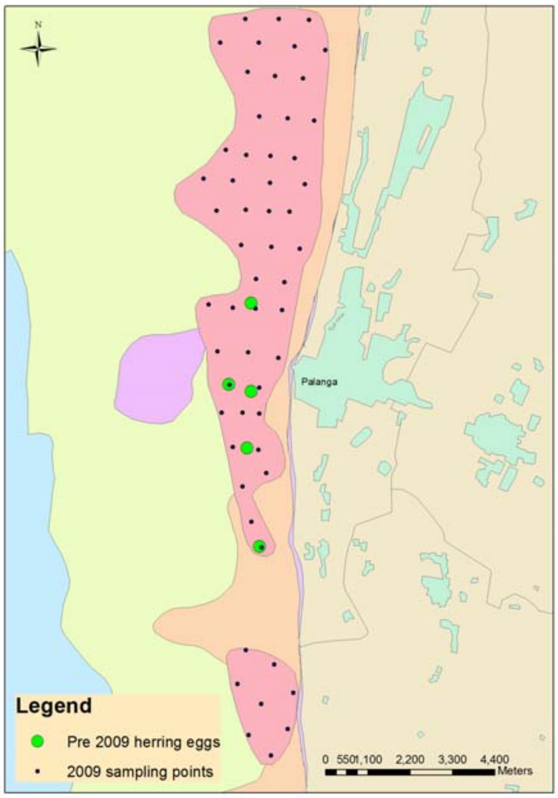

Figure 1. Sampling points during 2009 field season

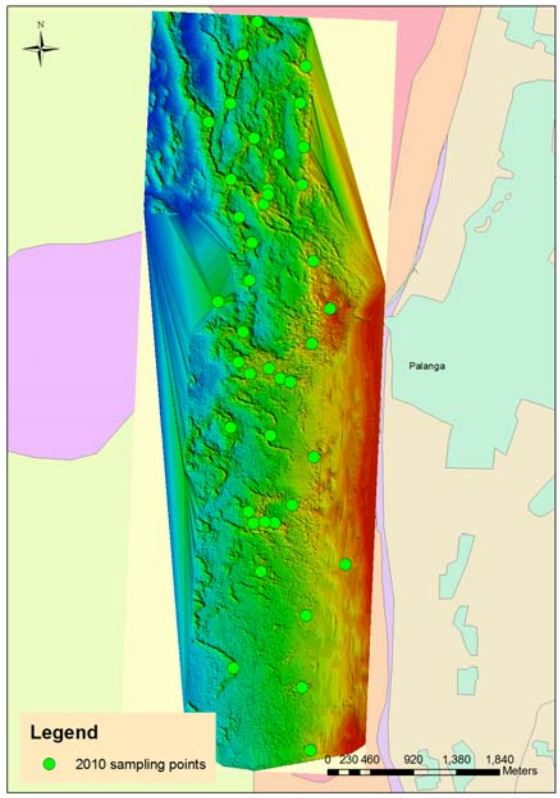

Figure 2. Sampling points during 2010 field season

5.2 Sampling and data processing

Baltic herring eggs are relatively small (<2mm) and semitransparent, therefore hardly (if at all) detectable by distant methods. For field data collection SCUBA diving was used.

On the bottom diver performed the following:

1. Determine presence or absence of the herring eggs

2. Describe and memorize main habitat characteristics: substrate types and composition, *M. edulis, F. lumbricalis, Polysiphonia, Cocotylus truncatus* cover
3. Bottom area (about 4 m^2) was filmed using High Definition Sony HDR-HC9 video camera in underwater housing. Recording format – 1080i
4. Collect a sample of benthic fauna and flora

To ensure that potentially suitable for the *F. lumbricalis* hard substrate is present in the sampling point, remote underwater video camera was used prior to SCUBA diver deployment (Fig. 3)

Figure 3. Deployment of remote underwater video camera (left) and preparation of SCUBA diver (right)

To reduce divers' workload, only one diver worked in one sampling point. To ensure safety, diver was attached to the boat with a rope. Second diver had full equipment set and was ready to assist at any time (Fig. 3).

In the lab video was analyzed and compared with diver descriptions of main habitat characteristics. If necessary, corrections were made. Bottom flora and fauna samples were reviewed using Nikon Eclipse E200 microscope. If herring eggs were present, their development stages were distinguished.

Additionally during 2009 season was performed a detailed inspection of two spawning grounds. Pair of divers plotted transects thru the spawning ground and surroundings. Bottom was filmed in 1080i format using High Definition Sony HDR-HC9 video camera, herring eggs presence or absence along the transects was noticed and qualitative samples of benthic flora and fauna were taken. In total 6 transects were inspected, they lengths varied from 46 to 149 meters, with average 92 meters (Appendix 2)

6 Results
6.1 Collected data

During 2009-2010 field seasons 95 locations were sampled by SCUBA divers. At five locations herring eggs were occasionally found during previous studies (Appendix 1; Table 1)

Table 1. Data on the diving censuses. N.a. - not available.

	Start date	End date	Number of locations	Min depth (m)	Max depth (m)
Pre 2009	n.a.	n.a.	5	6	11
2009 season	7 April	29 April	54	4	14
2010 season	19 April	7 May	41	3	10

During both seasons 24 spawning locations were discovered, and five additional points were known from the previous studies (Appendix 1; Fig. 4).

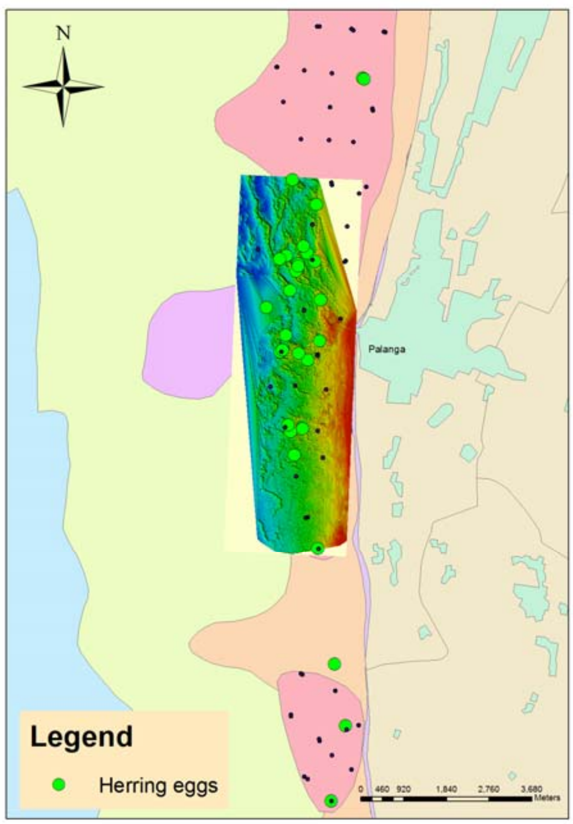

Figure 4. Herring spawning sites detected during this study.

6.2 Sampling points and spawning grounds distribution

During the study samples were collected from depth diapason 3 to 15 meters. Most samples were taken in depth interval from 5 to 10 meters, most suitable for *F. lumbricalis* in

Lithuanian coastal waters (Fig. 5). Herring eggs were detected down to 10.5 meters. Majority of eggs findings occur at depth interval from 4 to 9 meters (mean depth 6.86 meters), (Fig. 6; Table 2)

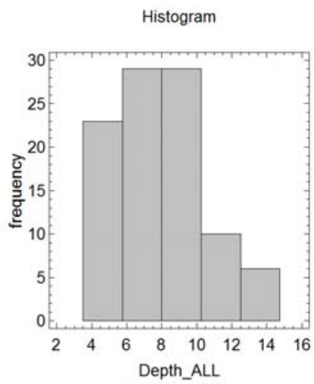

Figure 5. Depth distribution of sampling sites

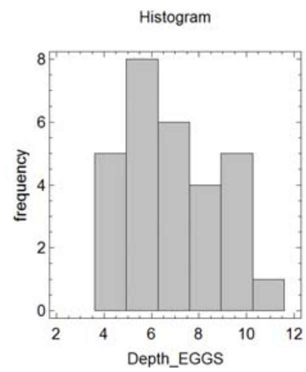

Figure 6. Depth distribution of spawning grounds

Table 2. Distribution of spawning grounds in relation to depth

Class	Lower Limit	Upper Limit	Frequency	Relative Frequency
	at or below	4	1	0.0345
1	4	5	7	0.2414
2	5	6	5	0.1724
3	6	7	5	0.1724
4	7	8	2	0.069
5	8	9	5	0.1724
6	9	10	3	0.1034
7	10	11	1	0.0345
8	11	12	0	0
	above	12	0	0

For the area where detailed bathymetry was available, simple geomorphological and shelter indexes were created and derived for each spawning locations:

Geomorphological index: 1 – top of the local elevation; 2 – non-elevated (descended) area; 3 – western slope of local elevation; 4 – eastern slope of local elevation.

Shelter index: 0 – not sheltered; 1 – sheltered from the West; 2 – sheltered from the East

Distribution of spawning sites according to those indexes is demonstrated on Fig. 7 and Fig. 8

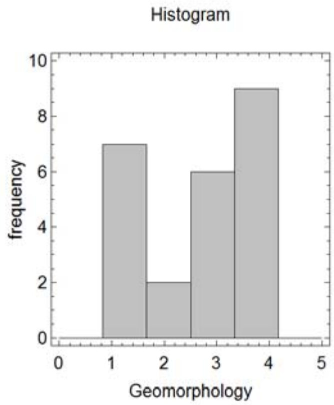

Figure 7. Geomorphological index for detected spawning grounds

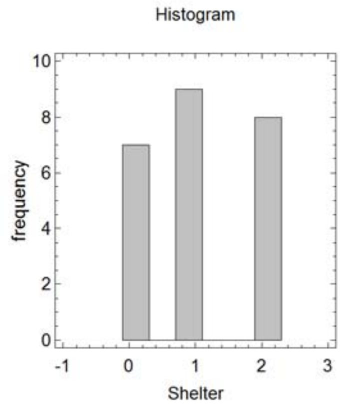

Figure 8. Shelter index for detected spawning grounds

6.3 Spawning substrate

During this study herring eggs were found on three different substrates: *F. lumbricalis*, *Polysiphonia* and *Mytilus edulis*. Majority of findings were on *F. lumbricalis* (Fig. 9, 10) (25 locations out of 29), then *Polysiphonia* (3 locations) and *M. edulis* and bare stones (1 location). However, in total 67 locations with significant cover of *F. lumbricalis* were discovered, therefore herring eggs were present only on 37.3% of potentially suitable locations.

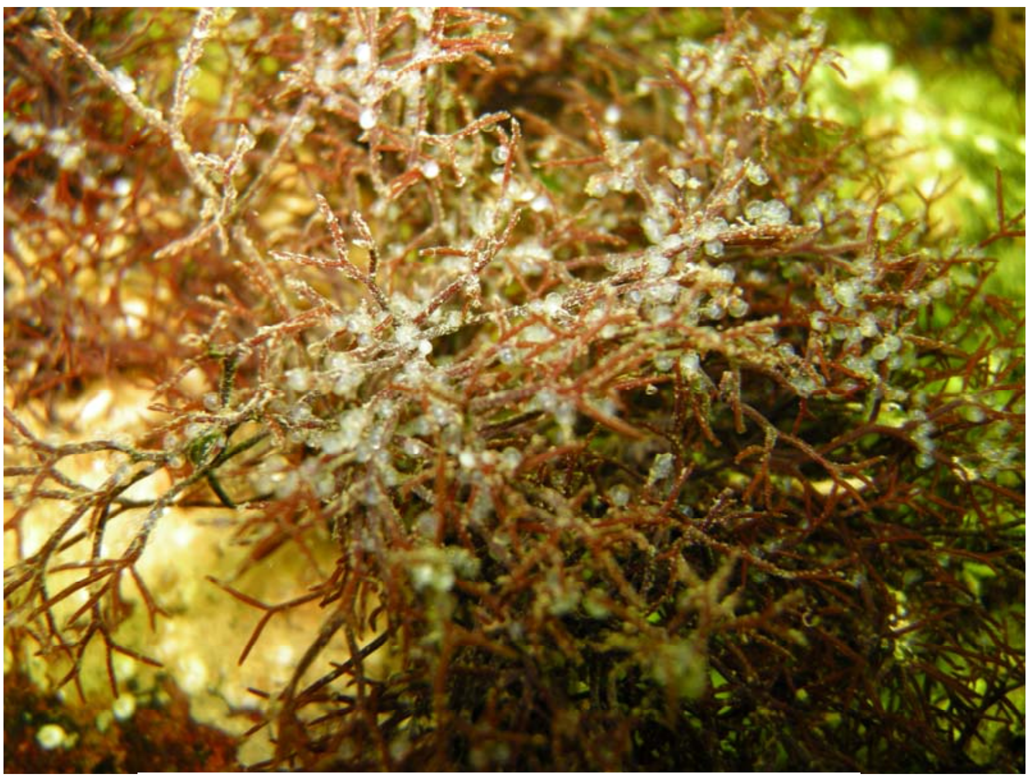

Figure 9. Herring eggs *in-situ* on *F. lumbricalis*

Figure 10. Herring eggs on *F. Lumbricalis* branch

6.4 Spawning efficiency

Because after the embryo dying, the eggs are detaching from the substrate and easily washed away by waves and water currents (Rajasilta et. al., 2006), it is problematic to evaluate eggs mortality using non-continuous *in-situ* data. Due to the limited resources and difficulties collecting field data, we were unable to take repeated samples for a large number of locations, and only three locations were visited twice.

To evaluate hatching progress, for collected samples an embryos development stages were distinguished according to Fig. 11 (Hill & Jonston, 1997)

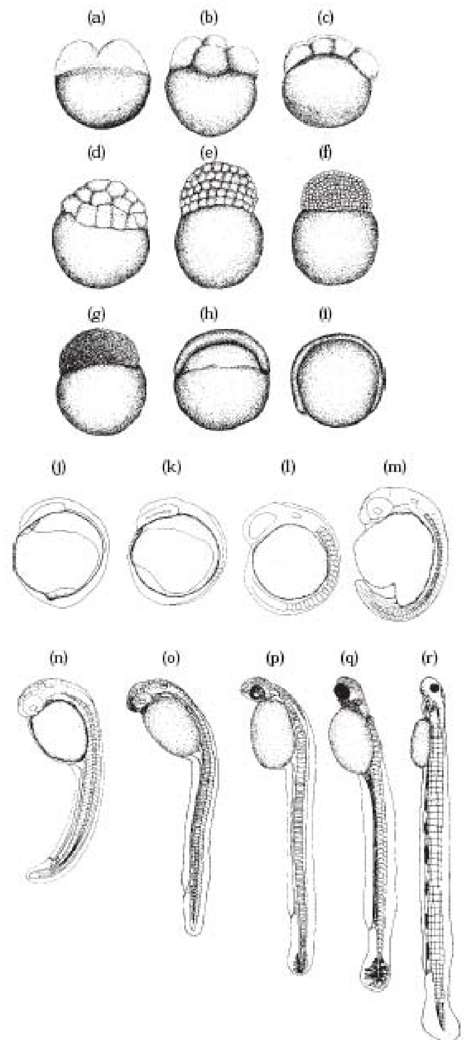

Figure 11. Stages of development of the Atlantic herring. (a) 2-cell stage; (b) 4-cell stage; (c) 8-cell stage; (d) 16-cell stage; (e) 64-cell stage; (f) mid-blastula; (g) late blastula; (h) 40% epiboly; (i) 90% epiboly. Yolk diameter (yd) (a)–(i) 900 ìm. (j) Neurula (yd: 850 ìm); (k) 3-somite (yd: 800 ìm); (l) 23-somite (yd: 800 ìm); (m) 42-somite (yd: 800 ìm); (n) 50-somite (total length, tl: 2·5 mm); (o) 62-somite (tl: 3 mm); (p) 85% eye pigment (tl: 4·5 mm); (q) eye coloured (tl: 5 mm); (r) hatch (tl:7 mm) (Hill & Jonston, 1997)

During the study embryos on the different stages of development (including the last stages) were obtained (Fig. 12 – 16).

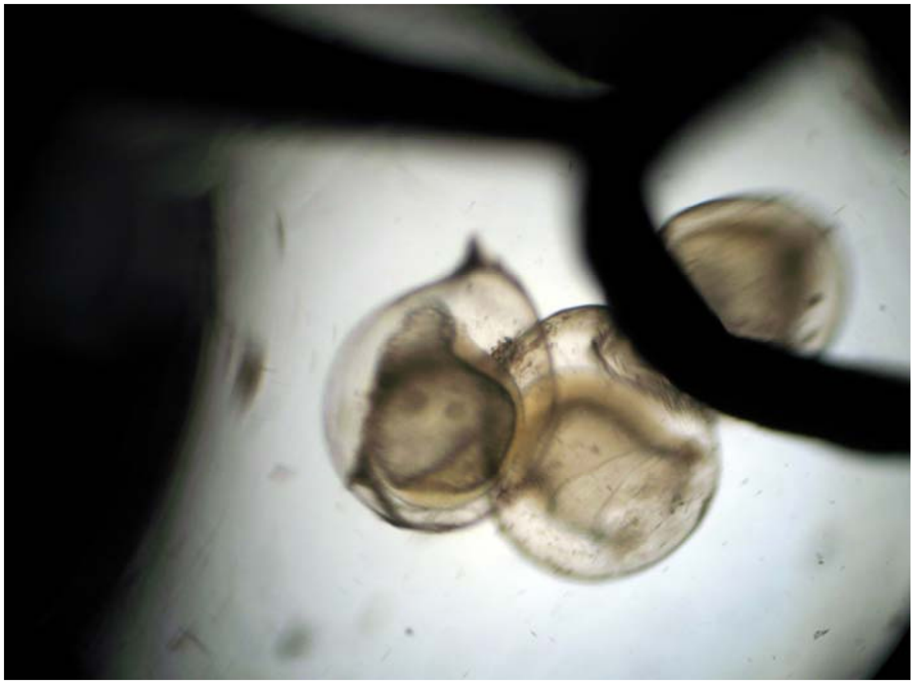

Figure 12. Herring embryos at the stage h-i.

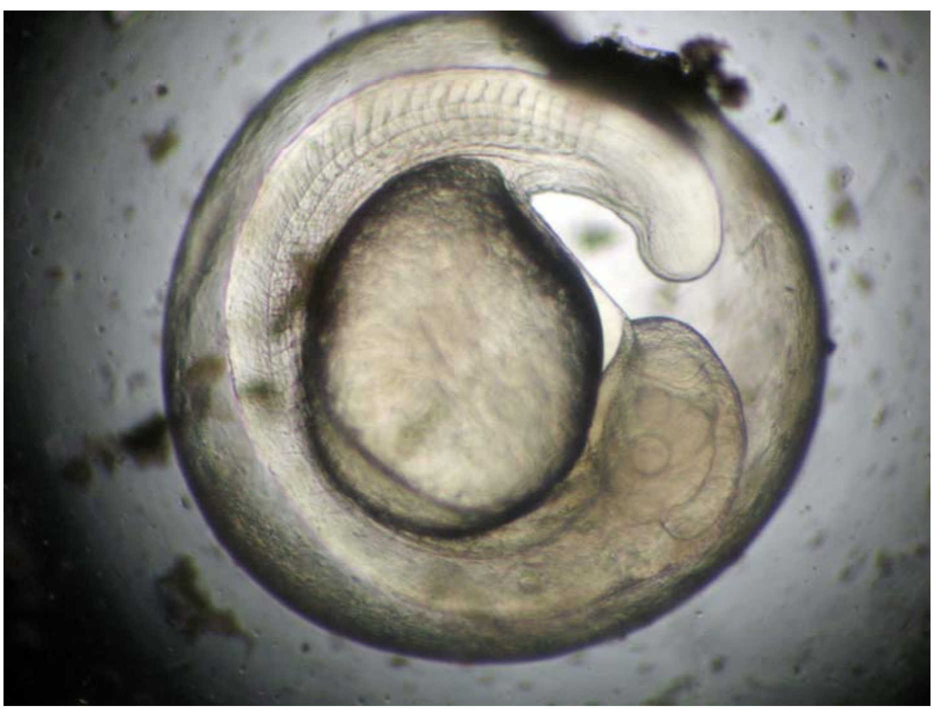

Figure 13. Herring embryo at the stage m-n.

Figure 14. Herring embryo at the stage n-o.

Figure 15. Herring embryo at the stage p-q.

The number of empty egg shells was found during the final 2009 season dives, this is indicate that spawning was successful (fig. 16)

Figure 16. Empty shells of the herring eggs.

During 2009 field season location D8 (Appendix 1) was visited 2009.04.21 and 2009.04.39. Locations A1 and A2 (Appendix 1) were visited 2009.04.07 and 2009.04.29. On the location D8 eggs were laying on *F. lumbricalis*, sample taken 2009.04.21 contained eggs with embryo stages m-n, while in 2009.04.24 – in later stage o-p, the latest stage before hatching.

Embryo stages of the eggs recovered from the locations A1 and A2 on 2009.04.07 were a-e. Eggs were found on *F. lumbricalis* in location A1 and on *M. edulus* and bare stones in location A2 (Fig. 17).

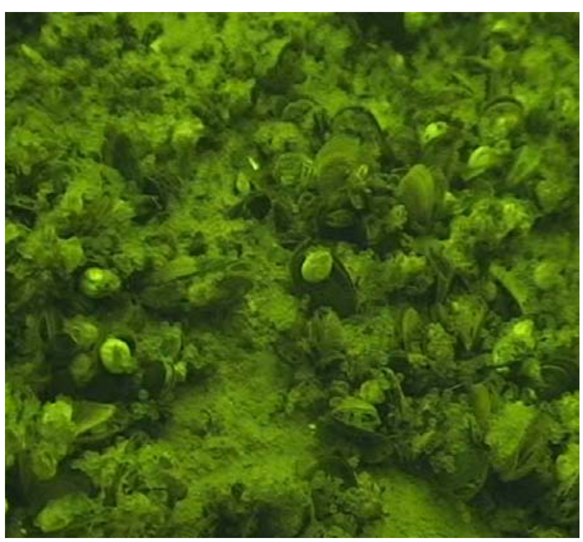

Figure 17. Herring eggs on blue mussels *M. edulis*

During the 2009.04.29 dive in location A1 were found eggs with embryos at the very last development stage p-q and already empty eggs shells. On the location A2, however, no eggs or empty egg shells were found. Because initial embryo stages for A1 and A2 location were the same, the A2 depth (8.5 m) is little bit greater than A1 (8 m), and they are not too far away one from another (980 m.), it is unlikely that there was a significant difference in the temperature regime between them. This leads to a conclusion, that absence of eggs or eggs shells in location A2 indicate unsuccessful eggs development and hatching.

3.5 Size and patchiness of the spawning grounds

To evaluate spawning grounds patchiness, detailed study of A1 and A2 spawning locations was performed. Five diver transects were made around A1 location and one around A2 (Fig. 18-19).

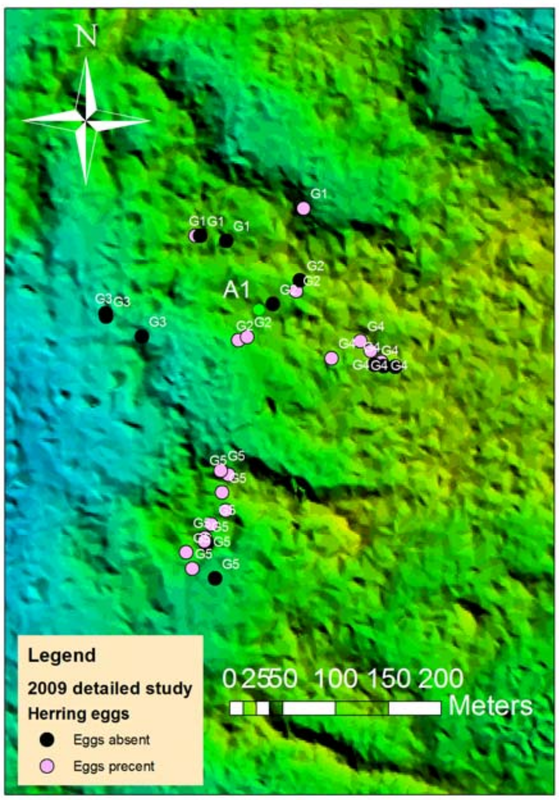

Figure 18. Spawning grounds around the area A1

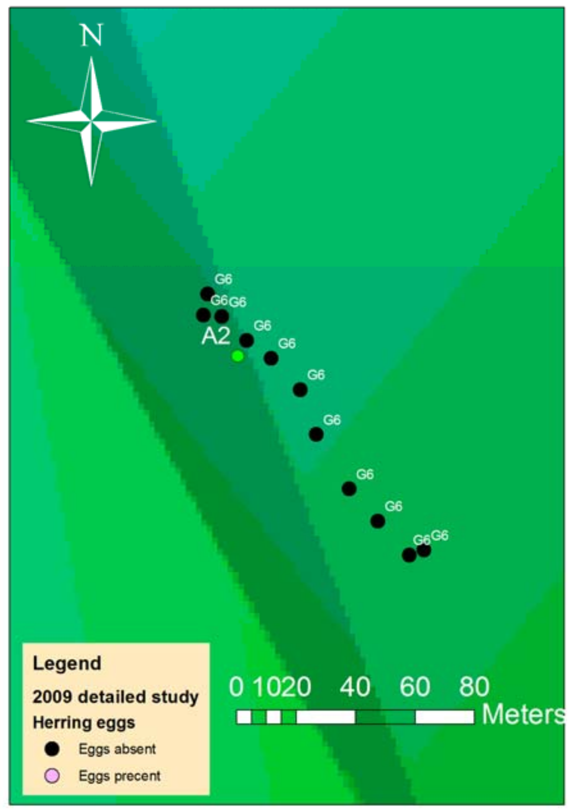

Figure 19. Divers trancect in location A2

According to those observations, herring spawning grounds in Lithuanian coastal waters could disappear and reappear again in proximity of just several hundred meters. Length of the single spawning ground in G5 transect was no less than 50 meters.

3.6 Start of spawning season

For many fish species start of the spawning triggers water temperature. Due to variety of spawning strategies of the herring in the Baltic Sea, this temperature is not the same for different populations. Water temperature (data form Marine Research Departament, Palanga station) and first eggs findings for 2009-2010 field seasons are shown on Fig. 20 and 21

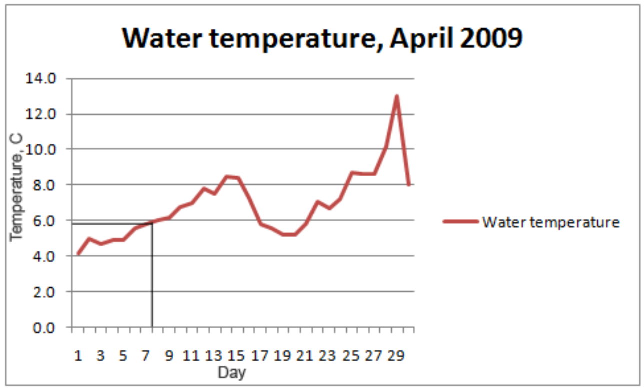

Figure 20. Water temperature near Palanga in April 2009 (data source: Marine Research Department) and first occurence of herring eggs

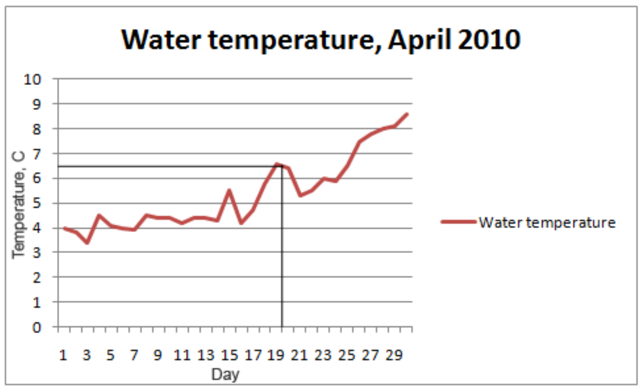

Figure 21. Water temperature near Palanga in April 2010 (data source: Marine Research Department) and first occurence of herring eggs

It is hard to make conclusions from two seasons, but for both years first herring eggs were found in period of one-two days after water temperature reached 5.6 – 5.8°C. The embryo stages in recovered eggs were one of the earliest (a-e), and from incubation experiments it is known that near 10°C embryo reach such development stages in approximately 23 hours (Veersalu & Saat, 2002).

4. Discussion

Conditions of the Lithuanian Baltic sea coast are not optimal for herring spawning – coastline is very exposed, with no sheltered areas. Probably this is a reason why herring spawn in relatively deep areas (average 6.8 meters, some goes down to 10.5 meters) (Fig. 6; Table 2).

It is known from a literature that different Baltic herring populations do not spawn at the same time, exhibiting a south to north cline in spawning times (Rajasilta et. al., 2006; Krasovskaya, 2002), which also is temperature depended (Jørgensen et. al., 2005). Spawning starting temperature 5.6-5.8°C detected during 2009-2010 field studies on the Lithuanian Baltic sea coast (Fig. 21-22) is in a good agreement with this trend. However, eggs collected on the first dives were already at some stage of development, and although incubation experiments tell as that those early stages can be reached fairly quickly (about 23 hours), those results are near 10°C temperature. And while in incubation experiment with 10°C mass hatching started after less than 10 days (Veersalu & Saat, 2002), in our case at sea condition hatching started after approximately 22 days of incubation, while mean water temperature was 7.3°C. Additionally, it is known that herring usually spawns in waves (Krasovskaya, 2002), therefore conclusions about spawning starting temperature in our case should be made with caution.

Due to the Curonian lagoon fresh waters interventions, salinity could change during eggs development. From the laboratory experiments it is known, that herring eggs can successfully develop in the wide range of salinities. However, salinity changes require changing of osmotic balance, stressful for the embryo, what indicate bigger oxygen consumption 6-8 hours after changing salinity (Holliday et. al., 1964). Another danger is high eutrofication of the Curonian lagoon waters. Heavy compositions of the decomposing organic masses (such as phytoplankton) could lead to very high herring eggs mortality (Morrison et. al., 1991). But during our study no abnormalities in embryos development were detected, and successful hatching was confirmed. However, spawning and incubation period is relatively short (22 days in relatively cold 2009 season (Fig. 20)), and during just two field seasons we could not encounter all possible environmental conditions. Therefore, even if there are no hard evidence that Curonian lagoon waters interventions negatively affects herring spawning, incubation and hatching in Lithuanian coastal waters, this possibility cannot be ruled out.

Herring spawning is not substrate specific (Aneer 1989), and in the Lithuanian waters herring eggs were detected on *Polysphonia*, *F. lumbricalis* and *M. edulis*. However, herring preferred 4-9 m depth range for spawning, where hard substrates are mostly occupied by *F. lumbricalis*, and majority of detected herring eggs (25 cases out of 29) were on this red algae. In one occasion herring eggs were found on *M. edulis* (Fig. 17), but during repeated survey eggs were absent, therefore there is no indication that hatching was successful.

Although red algae (such as *F. lumbricalis*) are reported to have a negative effect on the herring eggs (Rajasilta et. al., 1989, 1993, 2006), embryos in samples collected from *F. lumbricalis* were developing normally to the very last stages (Fig. 15), and successful hatches were detected (Fig. 16). It is known from a literature, that oxygen uptake of embryo is growing during development (Silva &Tytlerb, 1973). In the multilayer egg mats only one or two upper layers of eggs are successfully developing to the last stages, while deeper layers are aborting and/or show severe abnormalities of embryos (Messich & Rosenthal, 1989). Possible reason for this is a lack of oxygen (abortion stage is layer dependent, the deeper the egg, the earlier abortion stage (Messich & Rosenthal, 1989)). Due to the extended and well developed 3D structure of the *F. lumbricalis* branches it can accommodate a larger amount of herring eggs per unit area, while ensuring proper oxidization (Fig. 9-10).

Reviewing geomorphological indexes for a spawning location indicates only in few cases herring eggs were found in areas of local depressions (index value 2). Majority of spawning took place on the slopes or the top of the local elevations (Fig. 7). It seems that herring prefer shelter and western slopes, but the difference is relatively low in order to confirm such evidence (Fig. 18).

Choosing the model

Detailed study of the A1 location showed that distribution of herring eggs is patchy within distance of several hundred meters (Fig. 8), while divers could investigate an area of just several square meters due to high sampling intensity. It is much less than any meanfull grid size that could be used for modeling. More on that, in 2009 season C3 area (Appendix 1), which should represent a spawning ground according to the geomorphological hypothesis, herring eggs were not found during first dive 2010 season. To check if this is a real absence, several additional sampling points were set for this area, and herring eggs were found during third dive (2010 season, E5 (Appendix 1)) in this area.

Due to uncertainties of detected absences, percent-only methods should be more appropriate for modeling.

Bird's skeins theory

During the 2009 sampling season an idea that skeins of birds can be an indicator of the herring spawning grounds (Žydelis & Esler, 2005) was partially confirmed: in three additional sampling points (B10, F7 and F9; Appendix 1) which were selected by only birds presence on the water herring eggs were found. However, majority of the spawning grounds located during this study were not accompanied by bird's skeins.

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Appendix 1

Geographic positions of sampled points

X	Y	STATION	DEPTH	EGGS	SEASON
501585.34	6196683	A1	8	YES	2009
501196.57	6197584	A2	8.5	YES	2009
500965.33	6198829	A3	15	NO	2009
501581.91	6198719	A4	10.5	YES	2009
502005.65	6197567	A5	10	NO	2009
502146.12	6198712	A6	9	NO	2009
502850.8	6198666	A7	5	NO	2009
502797.19	6197414	A8	4	NO	2009
502338.61	6196624	A9	6	NO	2009
501643.02	6200344	B1	6.5	YES	2009
502173.6	6199842	B10	4	YES	2009
501781.23	6201232	B3	12	NO	2009
502380.13	6201246	B4	11	NO	2009
502904.81	6201221	B5	10	NO	2009
502478.18	6200331	B6	9.2	NO	2009
503079.04	6200126	B7	7.5	NO	2009
502848.56	6199403	B8	7.5	NO	2009
502108.98	6199416	B9	8	NO	2009
501887.88	6195936	C1	8	NO	2009
501357.7	6195894	C2	12.5	NO	2009
501839.22	6194947	C3	7	YES	2009
501985.47	6193998	C4	10	NO	2009
502236.23	6193115	C5	9	NO	2009
502536.37	6192460	C6	6	NO	2009
502550.48	6194425	C7	6	NO	2009
502405.27	6194989	C8	5	NO	2009
502553.56	6195889	C9	5	NO	2009
501369.64	6202018	D1	10	NO	2009
503298.64	6201915	D10	8.5	NO	2009
501198.57	6202764	D2	14	NO	2009
501788.23	6202711	D3	14	NO	2009
502383.58	6202680	D4	13	NO	2009
502070.71	6203672	D5	13	NO	2009
502798.79	6203620	D6	12	NO	2009
503487.36	6203605	D7	7	NO	2009
503052.06	6202598	D8	9.5	YES	2009
501726.14	6204879	E1	14	NO	2009
503733.5	6205462	E10	0	NO	2009
503086.53	6202579	E11	9	YES	2009
501972.67	6205587	E4	11	NO	2009
502451.11	6206200	E5	11	NO	2009
503241.84	6206211	E6	12	NO	2009

502884.51	6205523	E7	12	NO	2009
502434.8	6204721	E8	10	NO	2009
503301.57	6204606	E9	9	NO	2009
502306.39	6189748	F1	12	NO	2009
502104.68	6188850	F2	13	NO	2009
502514.09	6187517	F3	9.7	NO	2009
503045.88	6187055	F4	8.5	YES	2009
502738.93	6188344	F5	10	NO	2009
503017.38	6188048	F6	8	NO	2009
503285.63	6188692	F7	4.8	YES	2009
503309.29	6188618	F8	5	NO	2009
502995.62	6189984	F9	6	YES	2009
502060.7	6196527	A10	6	NO	2010
502556.67	6197295	A2	3	NO	2010
501692.6	6197973	A3	7.4	YES	2010
501545.1	6198240	A4	10	NO	2010
501684.32	6197560	A5	8.5	NO	2010
501358.57	6197317	A6	9	NO	2010
501639.47	6197007	A7	6.9	YES	2010
501602.22	6196680	A8	8.5	NO	2010
501843.13	6198551	B1	4.5	YES	2010
501937.48	6198932	B10	9	YES	2010
502378.76	6196918	B11	5	YES	2010
501439.68	6198638	B2	6	YES	2010
501666.8	6199087	B3	6	NO	2010
501173.06	6199241	B4	5.5	NO	2010
501399.19	6199454	B5	8.2	NO	2010
501512.12	6199980	B6	8.5	NO	2010
501648.77	6200338	B7	8	NO	2010
502186.95	6199885	B8	5.5	NO	2010
502142.8	6199489	B9	5.5	NO	2010
501982.03	6195912	C1	10	NO	2010
502842.19	6194563	C10	3.9	NO	2010
501550.22	6195978	C2	8.2	NO	2010
502066.69	6194982	C3	4.5	NO	2010
501838.59	6194963	C4	6.2	NO	2010
501937.62	6194448	C5	7	YES	2010
501690.19	6193403	C6	8.8	NO	2010
502555.21	6192556	C7	6	NO	2010
502433.28	6193224	C8	7.8	NO	2010
502447.98	6193998	C9	6	NO	2010
502354.53	6197800	E1	4.5	YES	2010
502168.54	6196492	E10	6	NO	2010
501797.83	6198389	E11	5.2	YES	2010
501842.4	6198497	E12	4.5	YES	2010
502203.94	6199019	E13	5	NO	2010
502200.33	6198616	E14	5	YES	2010

502456.33	6195701	E2	6.5	NO	2010
502246.42	6195176	E3	5.5	NO	2010
501961.45	6194984	E4	4.5	NO	2010
501782.64	6195087	E5	5.5	YES	2010
501731.03	6196563	E8	6.7	NO	2010
501934.95	6196627	E9	5	YES	2010
502027.26	6198789	P1	9.8	YES	Pre 2009
502090.93	6195014	P2	8.5	YES	Pre 2009
502134.6	6196494	P3	7	YES	Pre 2009
501539.67	6196647	P4	10	YES	Pre 2009
502524.49	6192458	P5	6	YES	Pre 2009

Appendix 2

Geographic positions of diver transects from 2009

Station	X	Y	Eggs
G1	21.02597	55.91646	YES
G1	21.02435	55.91619	YES
G1	21.02482	55.91616	NO
G1	21.02442	55.91619	NO
G2	21.02507	55.91531	YES
G2	21.02520	55.91534	YES
G2	21.02557	55.91563	NO
G2	21.02591	55.91575	YES
G2	21.02596	55.91584	NO
G3	21.02361	55.91531	NO
G3	21.02304	55.91549	NO
G3	21.02305	55.91546	NO
G4	21.02649	55.91519	YES
G4	21.02691	55.91535	YES
G4	21.02708	55.91527	YES
G4	21.02725	55.91518	YES
G4	21.02746	55.91514	NO
G4	21.02728	55.91514	NO
G4	21.02714	55.91515	NO
G5	21.02501	55.91416	YES
G5	21.02489	55.91419	YES
G5	21.02492	55.91401	YES
G5	21.02499	55.91386	YES
G5	21.02478	55.91373	YES
G5	21.02469	55.91362	YES
G5	21.02442	55.91348	YES
G5	21.02452	55.91334	YES

G5	21.02487	55.91327	NO
G5	21.02472	55.91355	NO
G5	21.02469	55.91358	YES
G6	21.01905	55.92379	NO
G6	21.01897	55.92385	NO
G6	21.01895	55.92379	NO
G6	21.01919	55.92372	NO
G6	21.01933	55.92367	NO
G6	21.01949	55.92358	NO
G6	21.01959	55.92344	NO
G6	21.01977	55.92328	NO
G6	21.01994	55.92319	NO
G6	21.02012	55.92309	NO
G6	21.02019	55.92311	NO