SALSEA-MERGE FP7-ENV-2007-1
Grant Agreement No 212529

Work Package 5

# Deliverable - D 5.2

# Report on analyses of the relationships between distribution of post smolts with physical and biological variables (D 5.2)

(Month 40)

# Introduction

This report gives a summary of the activities relating to the work carried under WP5 Task 5.1, Sub-task 5.1.2 Analysis of the distribution patterns associated with biological and oceanographic data

**Background**

During late spring and summer, Atlantic salmon smolts leave fresh water, and the post-smolts start their migration to their feeding areas in the ocean. This migration starts earlier in the south than further to the north. Hvidsten et al. (1998) suggested that smolts are adapted to leave the river when sea temperatures reach 8 °C, and this occurs about five weeks earlier in the south than in the north of Norway. After entering marine waters, the smolts migrate rather quickly through the fjords and into the ocean (Lacroix & McCurdy 1996; Thorstad *et al.* 2007), and their movements seem to depend on speed and direction of surface currents (Holm *et al.* 2004; LaBar, McLCleave & Fried 1978). Earlier surface trawl surveys in the Norwegain Sea have revealed a close association between post-smolt captures and the warm saline water typical of the North Atlantic Current, as almost all captures have been made in water salinities above 35 and temperatures between 8-11 °C (Holm *et al.* 2004; Holm, Holst & Hansen 2000).

Here, we analyze the relationship between catch of post-smolts with sea surface temperatures and salinity from the trawl surveys conducted during 2008 and 2009, ocean currents from the ocean model (ROMS), growth, zooplankton and other competitor fish distribution.

**Material and methods**

In total there were 286 trawl stations in 2008-2009 and 1727 post smolts were caught. In relation to the trawl stations 170 hydrographic stations were taken. For each trawl station the nearest hydrographic station, less than 12 hours difference in time and 100 km difference in distance, was used to calculate ambient sea surface temperature and salinity of the post smolts. Some trawl stations had also the same hydrographic station. For the temperature, 247 trawl stations fulfilled the requirements regarding the difference in time and space which included 1505 post smolts. For the salinity, the numbers are 128 trawl stations with 1420 post smolts. Post smolts were defined as all salmon with body length less than 35 cm. The numbers of captured post smolts within different temperature ($1^{o}$C interval) and salinity (0.1 intervals) ranges were calculated. The tow time for each trawl stations and the number of trawl stations within each temperature and salinity range were also considered.

Sea surface temperature data, satellite based data sets (Reynolds data set), were also used in the analysis. For biological data, the data sets that were used were growth data from salmon scales, while zooplankton and other fish competitor (herring and mackerel) distributions were taken from other surveys that covered the same area as the SALSEA-Merge surveys.

# Post smolts distribution and oceanographic parameters

### Post smolts and temperature

Fig. 1 shows that the captured postsmolts are mainly within 9-12 °C. However, in this range the number of trawl stations is also largest. In Fig. 2a we have averaged the number of post smolts captured per trawl hour within the different temperature ranges. This resulted in a larger spread of the data compared to Fig. 1. When we used the median (instead of the mean), the observed distribution is close to the normal distribution.

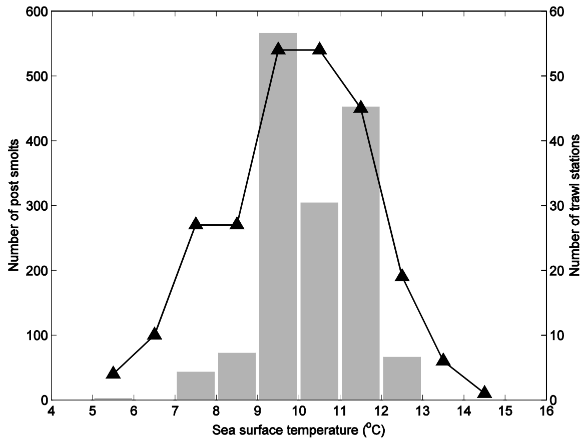


***Fig. 1.*** *Number of post smolts captured (grey bars) and number of trawl stations (triangles) within the different temperature ranges.*

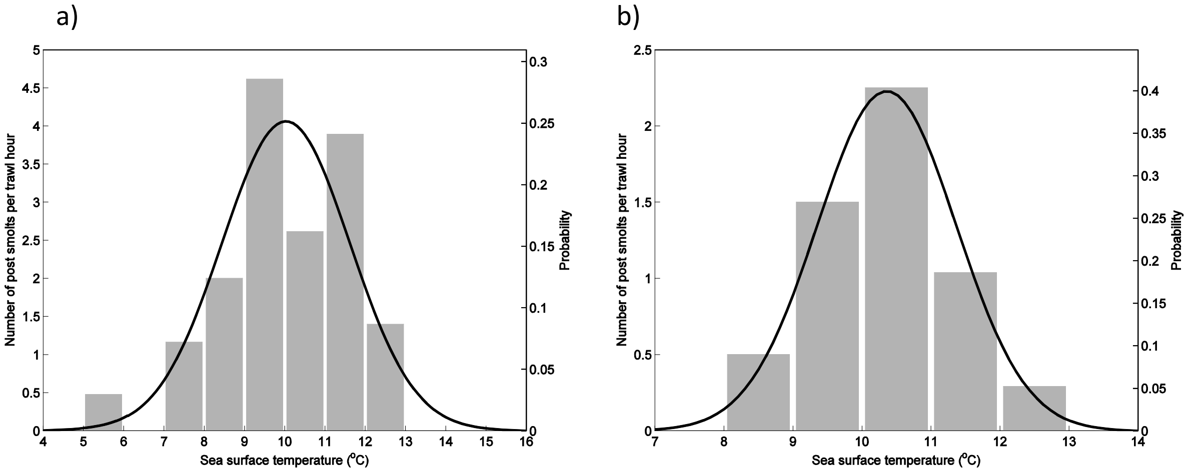


***Fig.2.*** *Number of post smolts caught per hour within different temperature ranges (1 °C interval). a) The numbers are averages within the different temperature classes. B) the same as a), but median is used instead of average. The weighted mean temperature and standard deviation is 10.0 °C and 1.6 °C for a), and 10.3 °C and 1.0 °C for b). The probability density function (thick line) is the normal distribution based on the different means and standard deviations.*

A goodness-of-fit test (using chi-square test) show $X^2$ = 391 and $X^2$ = 0.12 for the data in the left and right figure, respectively. This means that there is more than 95% probability (for n=7) that the observed distribution in Fig. 2b has a normal distribution. The data were also divided into two areas, one west of Ireland with latitudes less than 62°N and one for the other (i.e. the Norwegian Sea). The post smolts caught West of Ireland were in warmer water, mainly between 11 °C and 13 °C, than compared to the other (mainly between 8 °C and 11 °C) (Fig. 3).

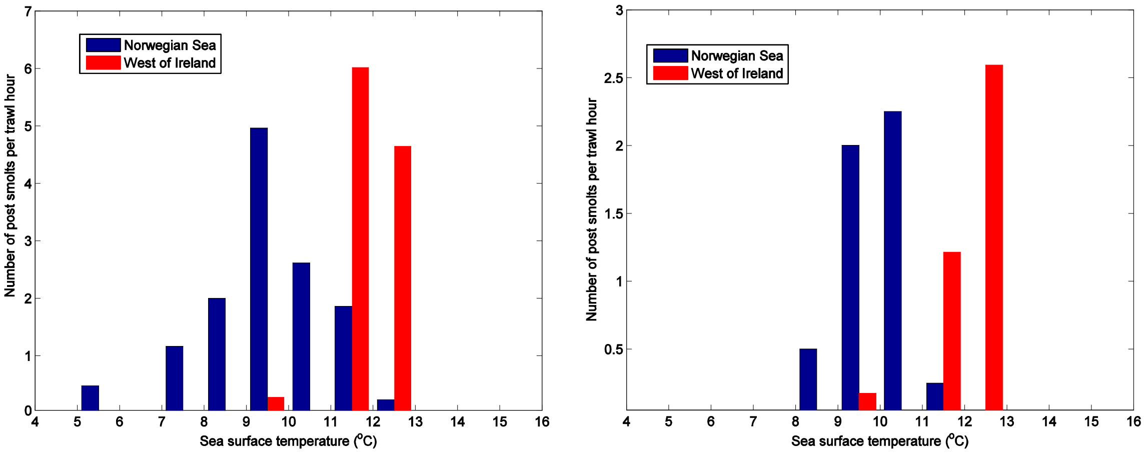


***Fig. 3.*** *Number of post smolts caught per hour within different temperature ranges (1 °C interval) divided into two areas: West of Ireland and the Norwegian Sea. Left figure: a) the numbers are averages within the different temperature classes. Right figure: b) the same as a), but median is used instead of averages.*

**Post smolts and salinity**

The same analysis was done for salinity as for temperature. There are several salinity ranges that have less than 5 trawl stations which mean that the analysis within these ranges must be taken with care (Fig. 4).

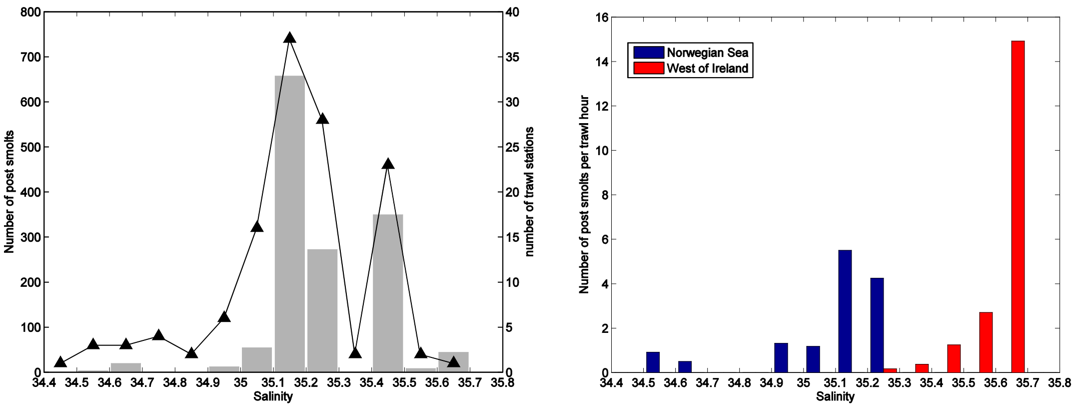


***Fig. 4.*** *Left: Number of captured post smolts (grey bars) and trawl stations (triangles) within salinity classes. Right figures: Number of post smolts catched per hour within different salinity ranges divided into two areas: West of Ireland (lat < 62°N) and the Norwegian Sea. The number of post smolts are averaged (using median) within the different salinity ranges.*

There are few post smolts in the less saline water (salinity < 34.9). The high value at salinity > 35.6 is based on only one observation/trawl station (see Fig. 4). An attempt to make a normal probability density distribution failed. Similar for the temperature the data are divided into two areas (West of Ireland and the Norwegian Sea), and similar as for the temperature, the post smolts West of Ireland are captured in water with the highest salinity (salinity larger than 35.2, and mainly larger than 35.4) (Fig. 4). The captured post smolts in the Norwegian Sea were all in water with salinity less than 35.3.

The distribution of sea surface salinity shows that coastal waters are spread offshore, particular from the Norwegian Coastal Current (Fig 5b). That catches of post smolts are much less over the Norwegian shelf (Fig 5a) may be a result that post smolts are avoiding the low salinity water, and instead move more offshore into Atlantic Water.

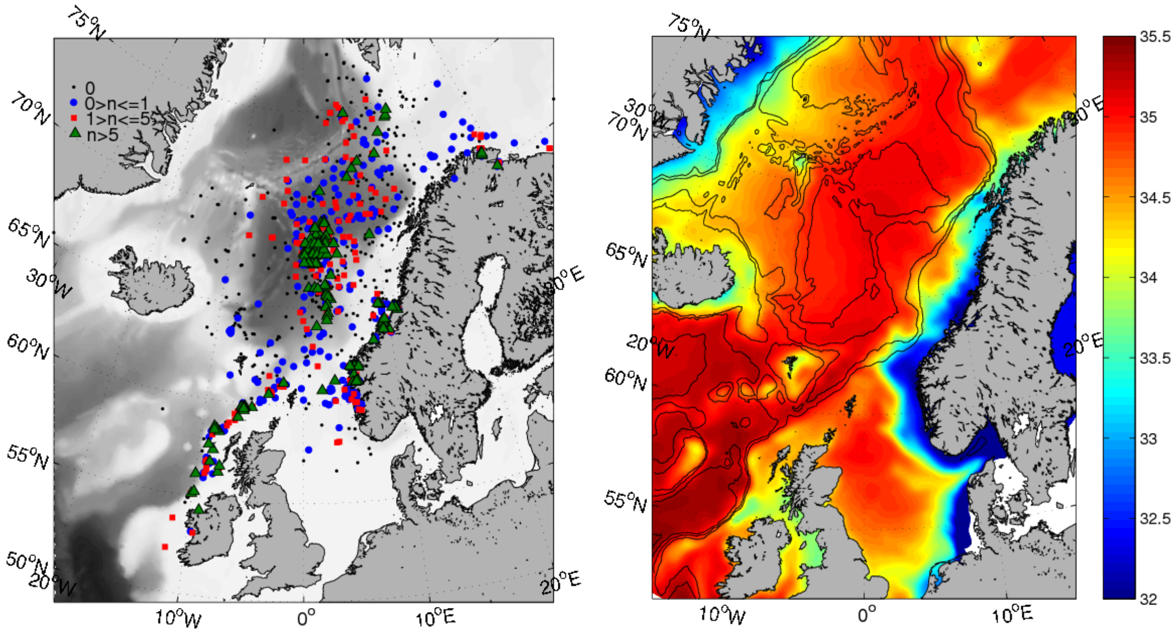


***Fig. 5.*** *Left: Number of captured salmon post smolts per trawl hour. All data (SALSEA-Merge + historical). Right: Surface salinity climatology for month May*

**Post smolts and currents**

It has been suggested that the post smolts use the currents during the migration. Based on the distribution of catches north of Scotland, the fish appeared to move northwards with the shelf edge current (Shelton et al. 1997). Farther north in the Norwegian Sea post-smolts were caught beyond 70° N in July, and analysis of growth and smolt age distribution strongly suggested that most of the post-smolts originated from rivers in southern Europe (Holst et al. 1996). Within this task we investigated the post smolt distribution in relation to surface current. At every trawl stations, from the SALSEA-Merge surveys in 2008 and 2009, that are in or in the vicinity of the migration path (band, see Figure 3 in the WP5 deliverable D5.3) the speed of the surface current was estimated from the ocean model (ROMS model, see the deliverable D5.3). Also, maximum and averaged speeds are calculated in the path, near the trawl stations. The speeds are averaged into two groups; all trawl stations with no catches and all trawl stations with one or more post smolts catches. This was also done for locations south of 61.5N and north of 61.5N.

Figure 6 shows that south of 61.5N the mean speed of the surface current at the trawl stations where post smolts were caught lies between the averaged and maximum speeds in the band. This suggests that post smolts are not random distributed within the migration path, but it instead prefers the locations where the currents are stronger than the average. North of 61.5N the mean speed of the surface current at the trawl stations where post smolts were caught lies approximately at the averaged speeds in the band. This can be due to either the post smolts seek the strongest current the first phase at sea (the migration phase) and less the next phase where maybe feeding is more important.

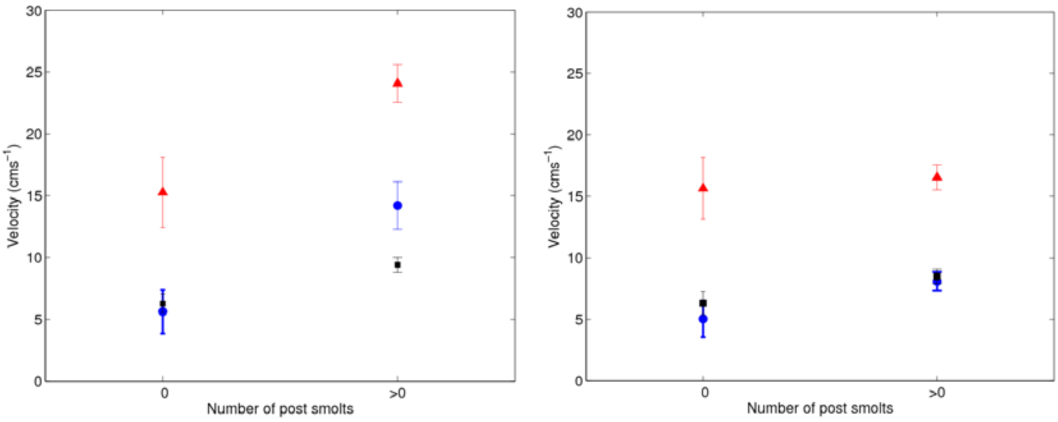


***Figure 6.*** *Averaged (black) and maximum (red) speed of surface velocity with error bars at and in the vicinity of the trawl stations within the migration path (from West Ireland to Lofoten Basin). Blue markers are exactly at the trawl stations. Data are from the SALSE-Merge surveys in 2008 and 2009. Left figure: trawl stations south of 61.5 N, 17 and 61 stations with 0 and >0 post smolts, respectively. Right figure: trawl stations north of 61.5 N, 26 and 76 stations with 0 and >0 post smolts, respectively.*

Next, the speed of the ocean surface currents at all trawl stations (both from SALSEA-Merge surveys and historical, see Fig 5a) were collected using the velocity fields from the ocean model. Again, the speeds were averaged into two groups: at trawl stations with post smolts catches and at trawl stations with no post smolts catches. The speeds were also averaged into intervals of 5 cm/s. The results show that there are only small differences between the two groups, except at the interval between 5 and 10 cm/s where there is larger percents of the first group (trawl stations with post smolts catches). Probably, most of the trawl stations are within the feeding area which makes it difficult to exploit the results. It seems most appropriated to divide the trawl stations into two cases; migration and feeding phases, which was done in the first case (Figure 6).

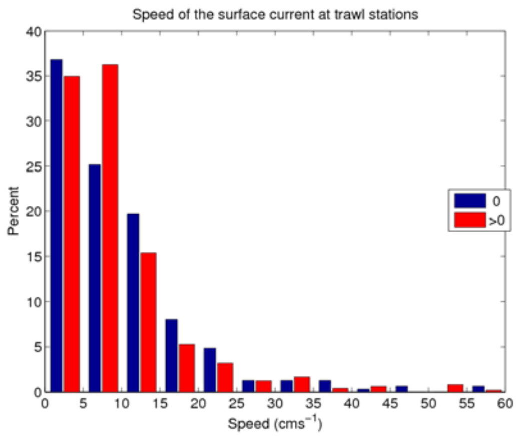


***Figure 7.*** *Percent of speed of the surface current for 5 cm/s interval. Blue colors are trawl stations with no post smolts while red colors are trawl stations where post smolts are caught. All data (SALSEA-Merge + historical) are used (see Fig. 5a).*

## Post smolts and growth

The smolt age of post-smolts was used as a proxy for origin, with older fish expecting to belong to more northern populations than younger fish. However, the relationship between catch per hour and sea temperature was not significantly different for post-smolts of age 1-4 years (Fig. 8).

The relationship between sea temperature at capture and growth rate the last month before capture was tested for post-smolts captured in the Norwegian Sea by using circuli spacings at the edge of scales of fish (Fig. 9). In post-smolts, circuli are formed at a rate of one circulus each 6.3 days during the growth period (see WP4). Hence, the sum of the five outermost spacings in the scales may be used as a proxy variable for growth in the last month before capture. In 2008, the growth rate increased with decreasing temperatures (Fig. 9) and increased with the latitude where the post-smolts were captured (Fig. 10). This suggests that growth increased with latitude, indicating increased food availability to the north. Fig. 5 and Fig. 6 both suggest that this was more pronounced in 2008 than 2009.

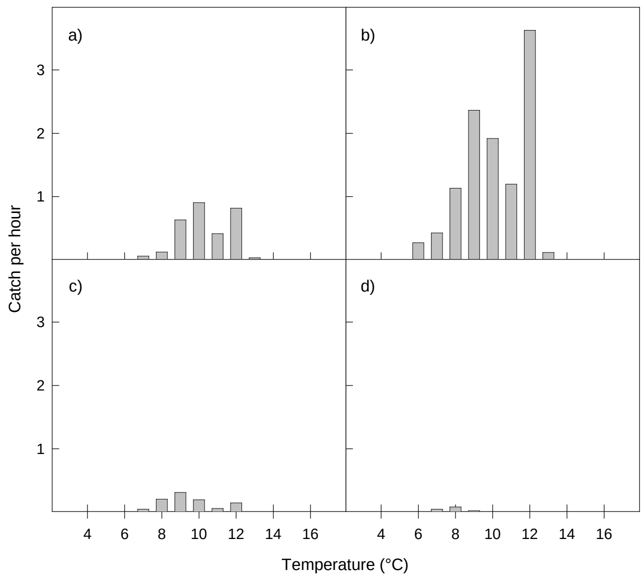


***Fig. 8.*** *Relationship between sea temperature (°C) and catch per trawl hour of wild post-smolts of different smolt ages. a) 1 year, b) 2 years, c) 3 years, and d) 4 years.*

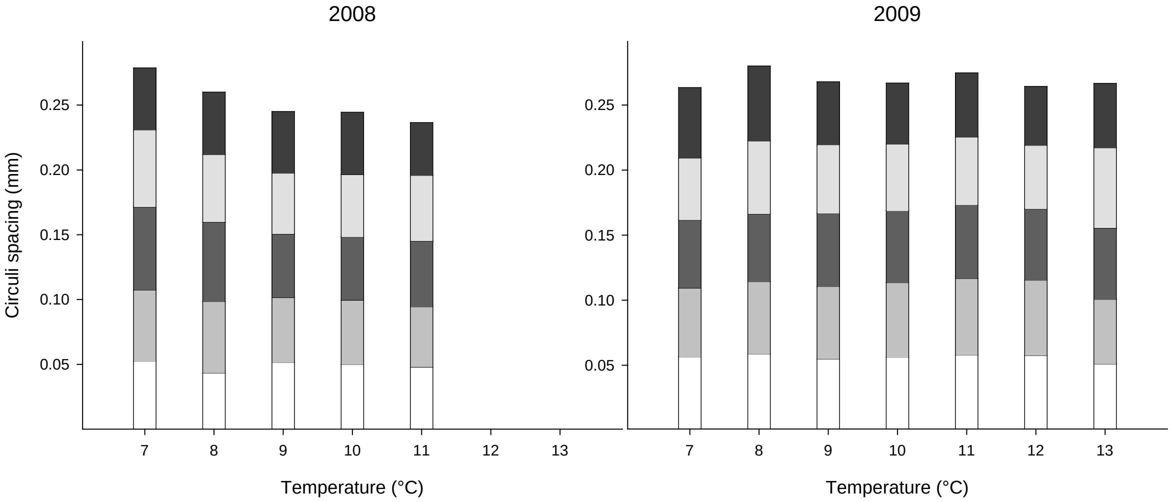


***Fig. 9.*** *Mean spacings (mm) between each of the five outermoust circuli in scales of post-smolts collected at different sea temperatures in the Norwegian Sea in 2008 and 2009, with the spacing closest to the edge of the scale at the top of the bar.*

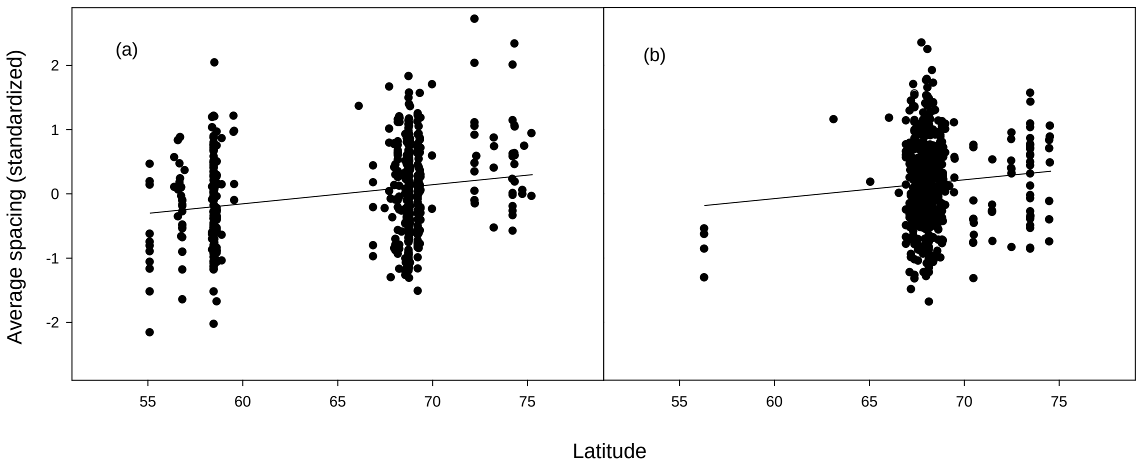


***Fig. 10.*** *Relationship between the latitude of the trawl stations and mean spacings in the five outermost circuli in scales of Atlantic salmon post-smolts collected in the Norwegian Sea in (a) 2008, and (b) 2009. Starting with the first marine spacing, distances were standardized before averaging. Regression lines: 2008: y = 0.030 x – 1.94,* $F_{1,\,501} = 28.45$, $r^2 = 0.052$, $p < 0.001$*; 2009: y = 0.029 x – 1.83,* $F_{1,\,603} = 4.02$, $r^2 = 0.007$, $p = 0.045$.

**Post smolts distribution in relation to zooplankton and other fish**

The main food of salmon are juvenile fish and the zooplankton species Themisto spp., but the diet of post-smolt salmon differs among year (see WP4 – deliverables regarding stomach content). However, because of lack of fish larvae data only zooplankton distribution from month May was possible, and only the data set from year 2009 was chosen within this report. In addition to zooplankton distribution spatial overlap between mackerel, herring, blue whiting and salmon in the Norwegian Sea between 15 July and 6 August 2009 are presented.

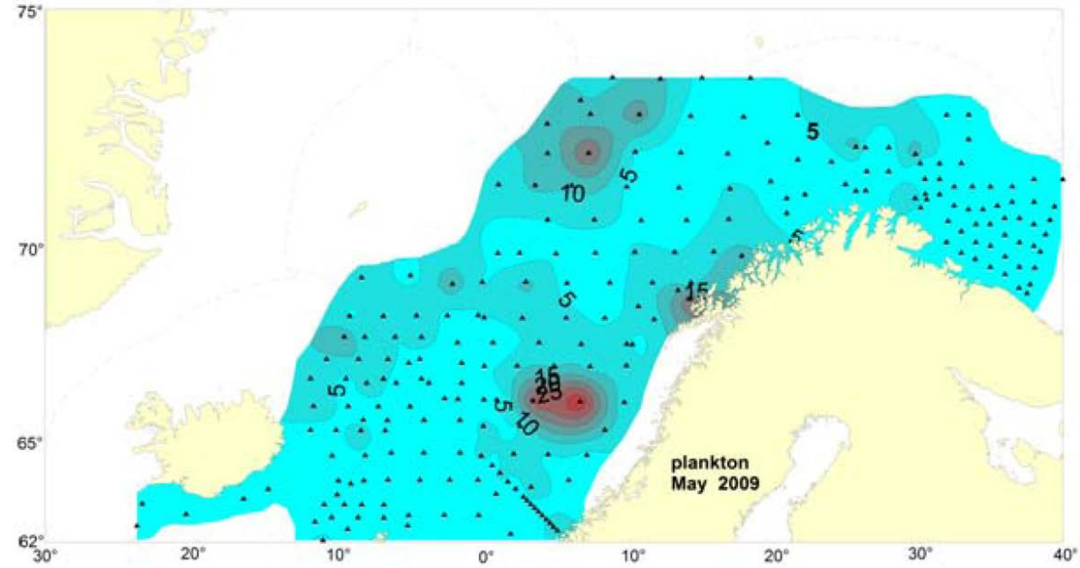


***Figure 11.*** *Zooplankton biomass (g dw m-2; 200–0 m) in May 2009.*

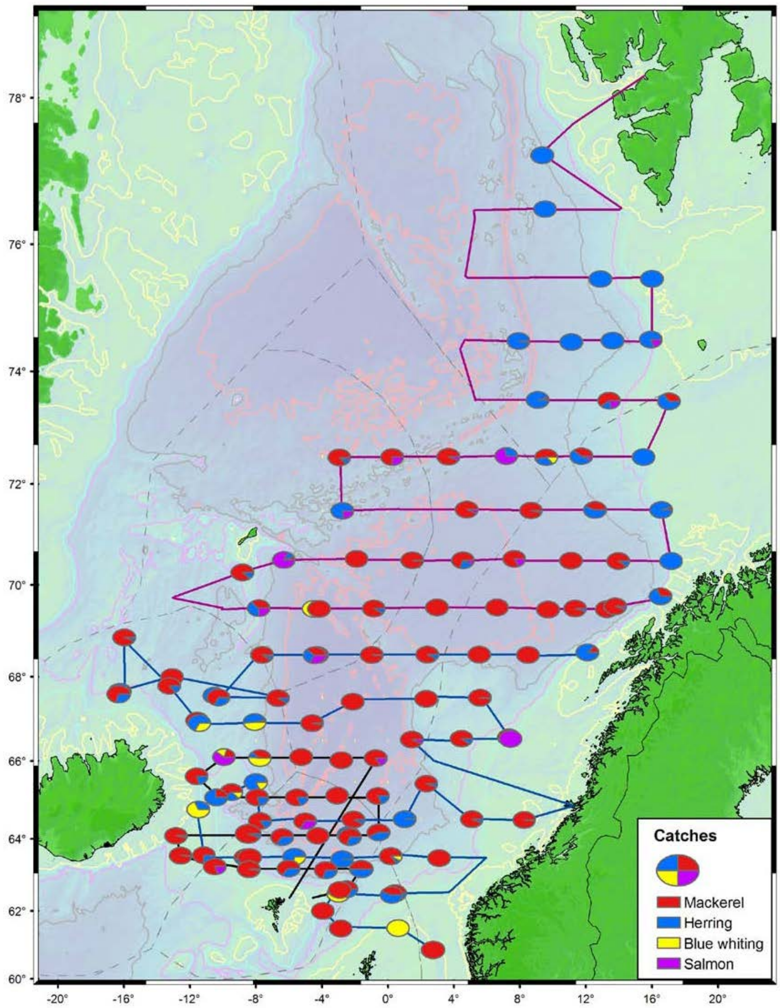


***Figure 12.*** *Distribution and spatial overlap between mackerel (red), herring (blue), blue whiting (yellow) and salmon (violet) in the Norwegian Sea between 15 July and 6 August 2009.*

Largest zooplankton biomass in May 2009 can be observed in the eastern and western areas of the Norwegian Sea, with low values in the southern areas. During the month May, the post smolts have still not migrated to the central Norwegian Sea and are located in this southern area. There is an overlap between the different fish stocks, and only at some few stations are salmon the dominated fish stock. In the northern Norwegian Sea the herring dominates while in the central and most of the southern Norwegian Sea mackerel dominates. This period, July/August, is the feeding period for salmon, and salmon, herring and mackerel have overlapping diets. However, herring and mackerel prefer the zooplankton species *Calanus finmarchicus,* and salmon very rarely eat that prey. In 2009 Themisto was the main prey for salmon (see WP4 – deliverables regarding stomach content). That salmon prefers other prey, e.g. like fish larvae and Themisto, it makes it difficult to do a comprehensive analysis between the post smolts distribution and its food or competitor fish stocks.

# Concluding remarks

Some of the observed relationships between post smolts distribution with other parameters are used in the development of the migration model (see the WP5 Deliverable D5.3). These relationships are:

- The preference of using the ocean current during migration
- The preference of temperatures between 9 and 11 $^{o}$C
- The preference of salinity larger than 35 (i.e. In Atlantic Water masses)

## References


Holm, M., Hansen, L.P., Holst, J.C., & Jacobsen, J.A. (2004). Atlantic Salmon, *Salmo salar* L. In *The Norwegian Sea Ecosystem* (ed H.R. Skjoldal), pp. 266-306. Tapir Academic Press, Trondheim.

Holm, M., Holst, J.C., & Hansen, L.P. (2000) Spatial and temporal distribution of post-smolts of Atlantic salmon (*Salmo salar* L.) in the Norwegian Sea and adjacent areas. *ICES Journal of Marine Science*, **57**, 955-964.

Hvidsten, N.A., Heggberget, T.G., & Jensen, A.J. (1998) Sea water temperature at Atlantic salmon smolt enterance. *Nordic Journal of Freshwater Research*, **74**, 79-86.

LaBar, G.W., McLCleave, J.D., & Fried, S.M. (1978) Seaward migration of hatchery-reared Atlantic salmon (*Salmo salar*) smolts in the Penobscot River estuary, Maine: openwater movements. *Journal de Conseil, International Council for the Exploration of the Sea*, **38**, 257-269.

Lacroix, G.L. & McCurdy, P. (1996) Migratory bahaviour of postsmolt Atlantic salmon during initial stages of seaward migration. *Journal of Fish Biology*, **49**, 1986-1101.

Thorstad, E.B., Økland, F., Finstad, B., Sivertsgård, R., Plantalech, N., Bjørn, P.A., & McKinley, R.S. (2007) Fjord migration and survival of wild and hatchery-reared Atlantic salmon and wild brown trout post-smolts. *Hydrobiologia*, **582**, 99-107.