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Schooling dynamics of Northeast Atlantic mackerel (*Scomber scombrus*) in the Norwegian Sea using multibeam sonar

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Summary: Pelagic fish in the Norwegian Sea perform seasonal migrations from overwintering, via spawning, to feeding grounds. Northeast Atlantic mackerel (*Scomber scombrus*) are highly migratory, fast-swimming, and an obligate schooling fish. Mackerel schooling dynamics in nature is unknown because they lack a swimbladder, resulting in a weak acoustic signature, and therefore are difficult to detect in the summer when in loose schools. However, high frequency omnidirectional SONAR is capable of detecting mackerel in the acoustic echosounder blind zone close to the surface. Mackerel schooling dynamics were studied in relation to temperature, zooplankton abundance and density of conspecifics in four geographically separate regions of the Norwegian Sea during summer. The thermocline depth had a profound influence on the depth distribution of schools. Mackerel were found shallower than 40 m depth where the temperature was at least 6° C. The fish generally swam north except for in the SW region, coinciding well with prevailing current directions. Fish were significantly larger in the north than in the south, and plankton abundance was higher in the west than in the east. The observed school dynamics in relation to abiotic and biotic factors were explained in terms of mackerel ecology during the summer feeding migration.

Introduction: Highly abundant stocks of pelagic fish migrate through the Norwegian Sea in the late spring and summer months on their annual feeding migration [1, 2, 3]. Many pelagic fish species migrate annually from overwintering, via spawning, to feeding areas during their lifetime. Northeast Atlantic (NEA) mackerel is a fast swimming pelagic fish with high endurance that is highly migratory, performing summer feeding migrations northwards from spawning grounds around 40-60° N to 72° N, but has been recorded even up to 75° N [4]. The distribution and abundance of NEA mackerel in this area has presumably varied considerably over the years and during the last decades depending on sea temperature and feeding conditions [3, 5]. Atlantic mackerel were found to prefer water at least 8° C in the Norwegian Sea [5]. NEA mackerel mainly occur in the upper 40 m of the water column during summer [6] and rely on light when selectively feeding on Calanoid copepods [5, 7]. The Norwegian Sea is bound by the warmer northerly Atlantic and coastal currents to the east and by the cooler southerly Arctic front to the west [1]. Energetic costs of migration can be offset by swimming with the tidal currents [6] or taking advantage of gyres and eddies. Schooling is common in pelagic fishes, and mackerel are a known obligate schooler. The advantages of schooling for small planktivores include: improved hydrodynamics, enhanced food finding and protection from predators [8]. Presently, little information exists regarding the behaviour of NEA mackerel because they are difficult to detect with acoustics equipment when in small, loose schools near the surface of the water because they lack a swimbladder. Small schools close to the surface are located in the echosounder acoustic blindzone; however, omnidirectional SONAR has been used successfully in the past to record migratory behaviour of schooling fish [6]. The main objective was to analyse the distribution, depth, swimming speed and direction, school size and clustering of NEA mackerel schools from July to August 2010 using an omnidirectional multibeam SONAR. These parameters were correlated with physical and biological data to examine their influence on schooling NEA mackerel during the summer feeding migration. Physical (temperature, currents) and biological (prey, potential predators) differences between northern and southern and oceanic and coastal regions were expected, hence, four geographically separate regions of the Norwegian Sea were selected for inter/intra-regional analyses.

[**1**] Skjoldal H.R. *et al.* (2004) The Norwegian Sea Ecosystem, Vol. Tapir academic press, Trondheim. [**2**] Huse G. *et al.* (2012) Effects of interactions between fish populations on ecosystem dynamics in the Norwegian Sea – results of the INFERNO project. *Marine Biology Research*, 8: 5-6, 415-419. [**3**] Utne K.R. *et al.* (2012) Horizontal distribution and overlap of planktivorous fish in the Norwegian Sea during summer 1995-2006, related to water temperature. *Marine Biology Research*, 8: 420-441. [**4**] Nøttestad *et al.* (2010) Cruise report from the coordinated Norwegian-Faroese ecosystem survey with M/V "Libas", M/V "Eros", and M/V "Finnur Fríði" in the Norwegian Sea and surrounding waters, 9 July – 20 August 2010. Working Document to WGWIDE, ICES 2-8 Sept. 2009. 49 p. [**5**] Iversen S.A. (2004) Mackerel and horse mackerel. *In:* Skjoldal H.R. (ed) The Norwegian Sea ecosystem. Tapir academic press, p.289-300.

Materials and Methods: Biological, oceanographic and acoustic data were collected from an ecosystem survey in the Norwegian Sea in July – August 2010. The combined purse seining and pelagic trawling vessel M/V "Brennholm" was employed. Four geographically separate regions [7, Fig 1]. The regions for analysis were chosen based on geographical separation in terms of latitude and longitude, SONAR data quality and mackerel abundance. Upcast temperature data from 50 m depth to the surface were used for analysis and compared with the mean school depths to evaluate the minimum temperature preference for NEA mackerel. The scrutinized acoustic segments occurred during daylight hours in each of the four regions, and one night time segment occurred in the NE region approximately 3 hours after (23 km east of) the daytime segment. The trawl catch from the nearest occurring pelagic trawl station with a proportion of at least 90% mackerel was used to confirm that mackerel was the species detected acoustically. LSSS was used for post-processing raw acoustic data. To minimize any potential vessel avoidance by mackerel schools, only schools within 85-300 m radius from the vessel were used; the goal being to detect and analyse schools exhibiting natural undisturbed swimming behaviours [9]. A module in LSSS, called PROFOS, provided means on school depth (m), speed ($m\ s^{-1}$), direction (°), area (m^2) and geographical school position (longitude and latitude). School area was used to estimate a relative school biomass by assuming that the schools were ellipsoid shaped and that the packing density was one fish per cubic metre. Meso-scale school clustering patterns in each region were compared in terms of nearest neighbor distance (NND). NND along 10 km of acoustic transect in each region was calculated as the two-dimensional distance from a school to its closest neighbouring school. Mackerel speed and direction were compared to the local prevailing current direction and speed to assess whether schools utilize the currents during migration. Mackerel length and weight, plankton biomass and marine mammal observations were also used for analysis.

Results and Discussion: The high mackerel stock in the Norwegian Sea during the summer allowed for many schools to be sampled during the survey period. In general, mackerel were distributed in the upper 40 m and in at least 6° C throughout the Norwegian Sea, during both day and night. There were regional differences in both depth distribution and sea temperature. Temperature was the main factor determining school depth in the NW as a result of cooler sub-surface sea temperature, but feeding conditions and light levels were probably the driving forces behind the depth distribution in the SE. Larger mackerel in the northern regions formed larger schools compared to in the southern regions. School swimming speed after subtracting the local prevailing current was on average 1.33 $m\ s^{-1}$; however, the average school speed (including the current) was 1.44 $m\ s^{-1}$. Mackerel lack a swimbladder and must swim constantly to avoid sinking and maintain a constant depth. The prevailing sea currents in the NW, NE and SE were in a northern direction, and most of the schools were found swimming with the current. However, the current was to the south in the SW region, suggesting a gyre. The schools also swam with the current in this region. The schools in the SW were the smallest of the four regions, and swam the fastest. Plankton biomass was the lowest in this region, which has been linked in the past to fish swimming speed in a previous study [10]. The spatial distribution of mackerel in each region probably reflected dynamic trade-offs between available food in combination with potential predator threat and experienced temperature regime. Lack of potential predators may have resulted in smaller and looser schools adapted to limited food. In the north, mackerel schools were large; a common response to predation pressure. However, food abundance was high in the NW so it was probably not necessary to dissolved into smaller schools. Even without predation pressure in these four regions, the schools in the north probably traded off safety over maximizing feeding as a result of close to record low levels of zooplankton abundance in the Norwegian Sea in 2010 [2]. Future studies should consider: reducing vessel speed to perform target tracking, choose a smaller dedicated study area, and include data from the southern distribution of mackerel in the North Sea.

[**6**] Godø *et al.* (2004) Behaviour of mackerel schools during summer feeding migration in the Norwegian Sea, as observed from fishing vessel using SONARs. *ICES J Mar Sci.* 61: 1093-1099. [**7**] Langøy *et al.* (2012) Overlap in distribution and diets of Atlantic mackerel (*Scomber scombrus*), Norwegian spring-spawning herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*) in the Norwegian Sea during late summer. *Marine Biology Research*, 8(5-6): 442-460. [**8**] Pitcher and Parrish (1993) Functions of shoaling behaviour in teleosts. In: Behaviour of Teleost Fishes 2nd edn. Edited by Tony J. Pitcher. Chapman and Hall, London. p. 363-439. [**9**] Misund *et al.* (1997) Migration behaviour of Norwegian Spring Spawning herring when entering the cold front in the Norwegian Sea. *Sarsia* 82: 107-112. [**10**] Macy *et al.* (1998) Effects of zooplankton size and Concentration and light intensity on the feeding behaviour of Atlantic mackerel *Scomber scombrus*. *Marine Ecology Progress Series*, 172: 89 – 100.