BLACK SEA ANCHOVY *(ENGRAULIS ENCRASICOLUS PONTICUS)* TRANSPORT PATHWAYS

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Abstract
Overwintering migration of Black Sea anchovy from the northwestern shelf to the southeast coast of the Black Sea is investigated using a Lagrangian particle-tracking model. By releasing drifters into surface currents calculated from satellite data, transport pathways of anchovy were simulated during different years and seasons. Simulations included different types of swimming behavior. Dominant pathways for anchovy to migration towards the southeast are suggested as direct transport from the Crimea south, transport along the Eastern Gyre following the Rim Current and transport across the Eastern Gyre.

Keywords: Black Sea, Migration, Models

Introduction
Anchovy migration in the Black Sea is not well understood and contrasting theories on overwintering migration exist. One theory is that anchovy are doing extensive overwintering migration from the spawning ground at the northwestern shelf to the southeastern coast of the Black Sea by beginning of October [1] or early autumn [2], while others suggests that anchovy spawning grounds are located in the southern region [3] and hence only local anchovy of the southern Black Sea migrate to this overwintering ground. Also it is know that anchovy migration is driven by ambient temperature criteria [1]. The present work focuses on elucidating which migration routes are feasible for anchovy to complete successful migration to the overwintering grounds depending on the interannual variability of ocean currents and sea surface temperature distribution.

Methods
Surface circulation fields were calculated from AVISO (Archivinig, Validation and Interpretation of Satellite Oceanographic data) sea surface height anomaly data. A Lagrangian particle-tracking model was used. Sea surface temperature optimal was obtained from AVHRR (Advanced Very High Resolution Radiometer) temperature product for the Black Sea. A total of 1026 drifters were launched along the northwestern shelf at different times during autumn of different years (2001-2003) that span a variety of environmental conditions in the Black Sea. To account for behavior, directional swimming with differential swimming speeds and directions (i.e. SE, ESE, SSE) were added on top of advection to test how many drifters arrive successfully to overwintering rounds and in what amount of time. Temperature thresholds of 13.5^{o}, 15^{o} and 17^{o}C were tested as the maximum allowable temperature for them to start active migration.

Results
Sea surface temperature varies greatly between years and is known to influence anchovy migration. Using 17^{o}C as threshold below which anchovy migration starts defines areas from which anchovy may start migration. Choosing lower temperature thresholds allowed no migration in the years of interest during fall. Directional swimming towards ESE at 1-2.5 body length per second is the most successful swimming behavior.

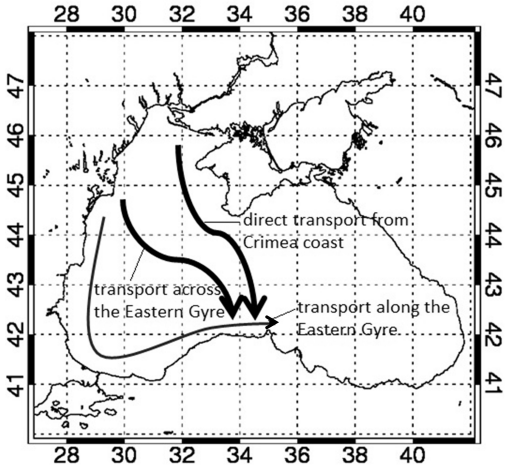

Fig. 1. Conceptual figure of anchovy pathways.

Three different pathways identified for anchovy migration (Fig.1): 1) direct transport from Crimea to the Turkish coast midway between the Eastern and Western Gyre, 2) transport along the eastern and then the southern edge of the Eastern Gyre following the Rim Current, and 3) transport through the Eastern Gyre. Moreover, anchovy located near the Danube plume, Kali-Akra and Constantsa regions of the NWS, prefer transport pathways 1, 2, and 3, respectively. Furthermore, the Danube and Sevastopol eddies and the cyclonic quasi-stable inner cell, as well as the Sinop and Kizilirmak eddies enhance anchovy transport.

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