SUN-COMPASS ORIENTATION IN MEDITERRANEAN FISH LARVAE

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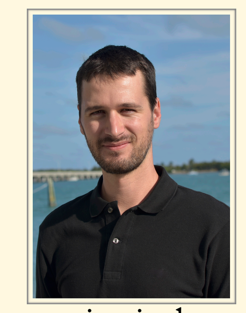

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The Drifting In Situ Chamber (DISC)

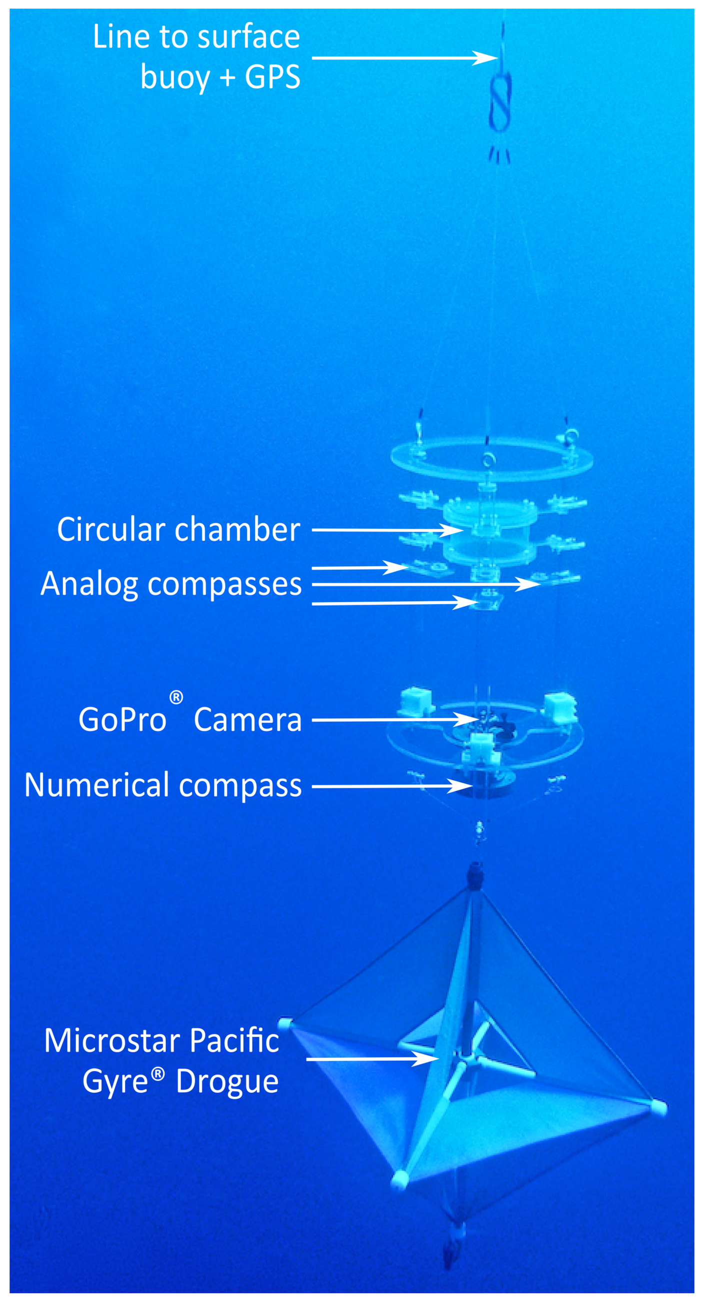


Fig 1. The Drifting In Situ Chamber (DISC) during a deployment.

The DISC is a lagrangian gear that has been developed to observe the orientation behavior of organisms *in situ*, without the potential bias of the presence of an observer. It is described in Paris et al. (2008) and presented in Fig. 1. The DISC drifts with the water mass just like a larva would do in its natural environment, and the behavioral chamber is made of mesh for the larva to be able to detect external cues (eg. sounds, wave direction, predators, etc.).

DISC data processing

The raw data recorded are images of the behavioral chamber in which the larva swims, and the compass data, GPS position and temperature and luminosity measurements. All data are first synchronized, then the position of the larva is tracked manually over the 15 min of the deployments (Fig. 2, Raw). The trajectory of the larva is then corrected for the rotation of the DISC, providing the bearing maintained by the larva (Fig. 2, Corrected). Data processing is done with the R package "DISCr".

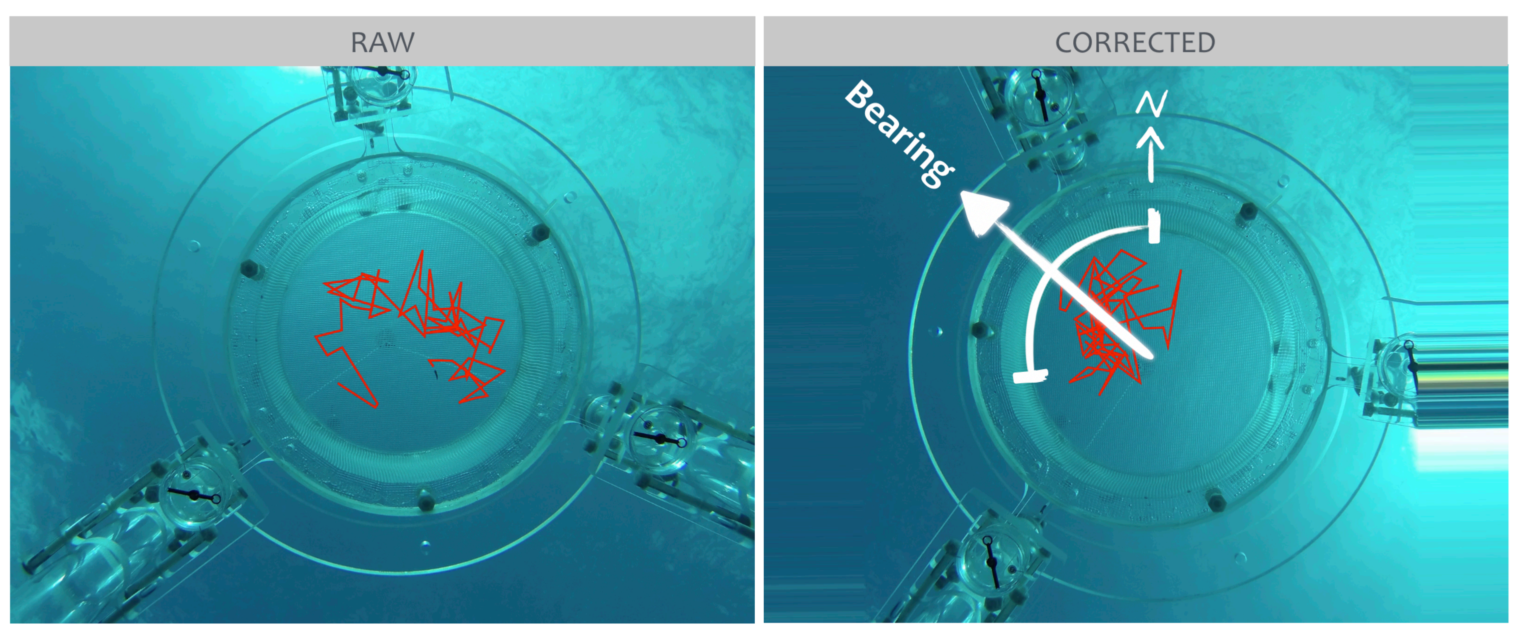


Fig 2. Example of trajectories within the referential of the chamber (raw trajectory) and after correcting for the rotation of the DISC (corrected trajectory).

Larval Fish Orientation

Mortality is very high during the pelagic larval phase of fishes but the factors that determine recruitment success remain unclear and hard to predict. Because of their bipartite life history, larvae of coastal species have to head back to the shore at the end of their pelagic episode, to settle. Passively drifting with the currents may not enable fish larvae to find suitable settlement habitats, and so it has been hypothesized that they may orient once reefs become detectable. In a laboratory experiment, post-settlement stage individuals of a tropical species responded positively to solar cues (Mouritsen et al. 2013) and to magnetic cues (Bottesch et al. 2016). How do they orient in the wide, blue ocean still remains unsolved, however.

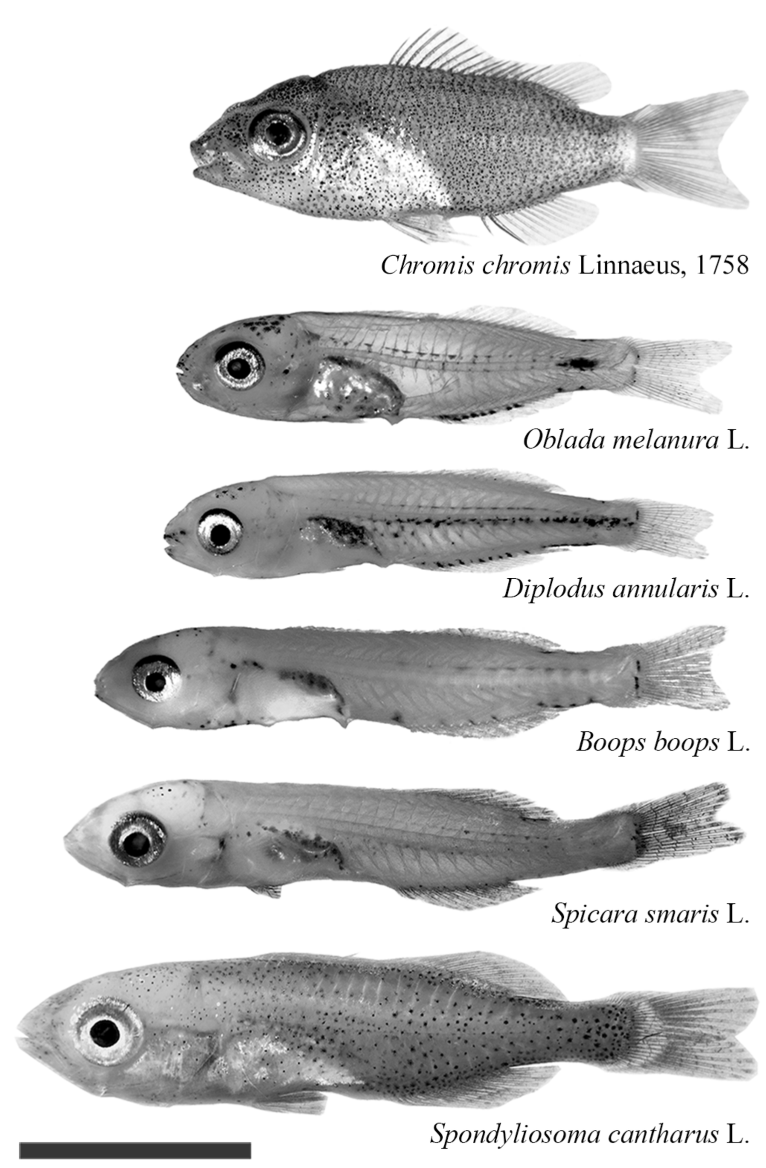


Fig 3. Morphology of the settlement-stage larvae of the six species tested. Size is proportional to median standard length (scale bar = 5 mm).

Study Site: The NW Mediterranean Sea

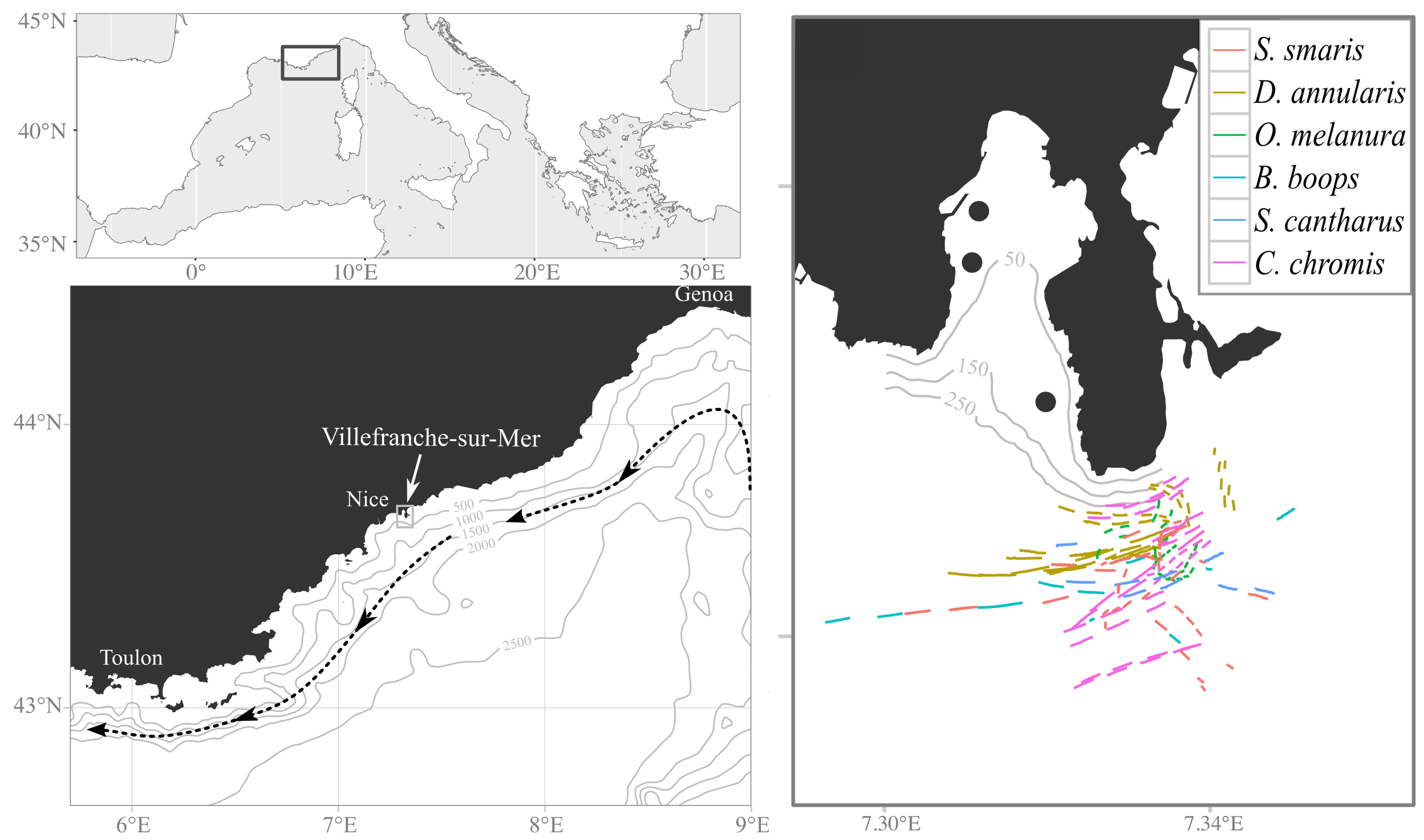


Fig 4. General location of the study area (top left panel), zoom on the region of interest with the location and direction of the Ligurian current (bottom left panel), and detailed map of collection sites (black dots) and deployments conducted for the study (right panel). Segments represent the drifting trajectories of the instrument over each of the 182 deployment. Grey lines indicate the isobaths.

Results: Fish Larvae Track Solar Cues

- Most (89%) larvae compensated for the rotation of the DISC and followed a cardinal direction instead (Fig. 5)
- The larger the larva, the more accurate its orientation (Fig. 5)
- The precision of orientation decreases with the sun visibility: it is lowest under clouded skies and highest under clear skies (Fig. 6)
- Fish larvae do not only use the sun to follow a random bearing, but they orient regarding to the sun's position in the sky (Fig. 7)

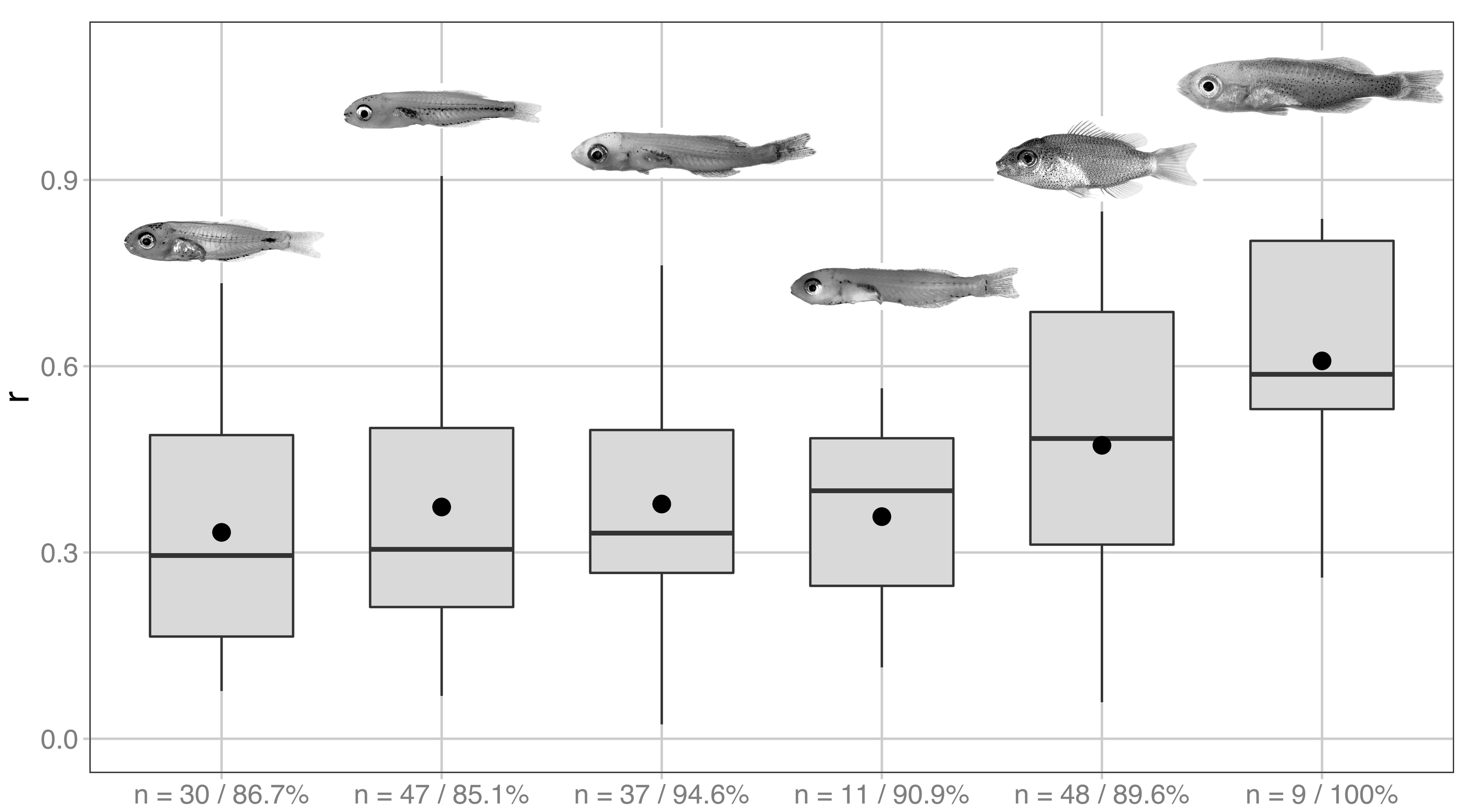


Fig 5. Strength of directionality (Rayleigh's r) of the six species tested. Sample size (n) and proportion of directional larvae (%) are indicated along the x-axis. Standard boxplots (median, interquartile range, and total range) are supplemented with black dots representing mean r values. Will the larval identification workshop help to identify these larvae, without using Fig. 3?

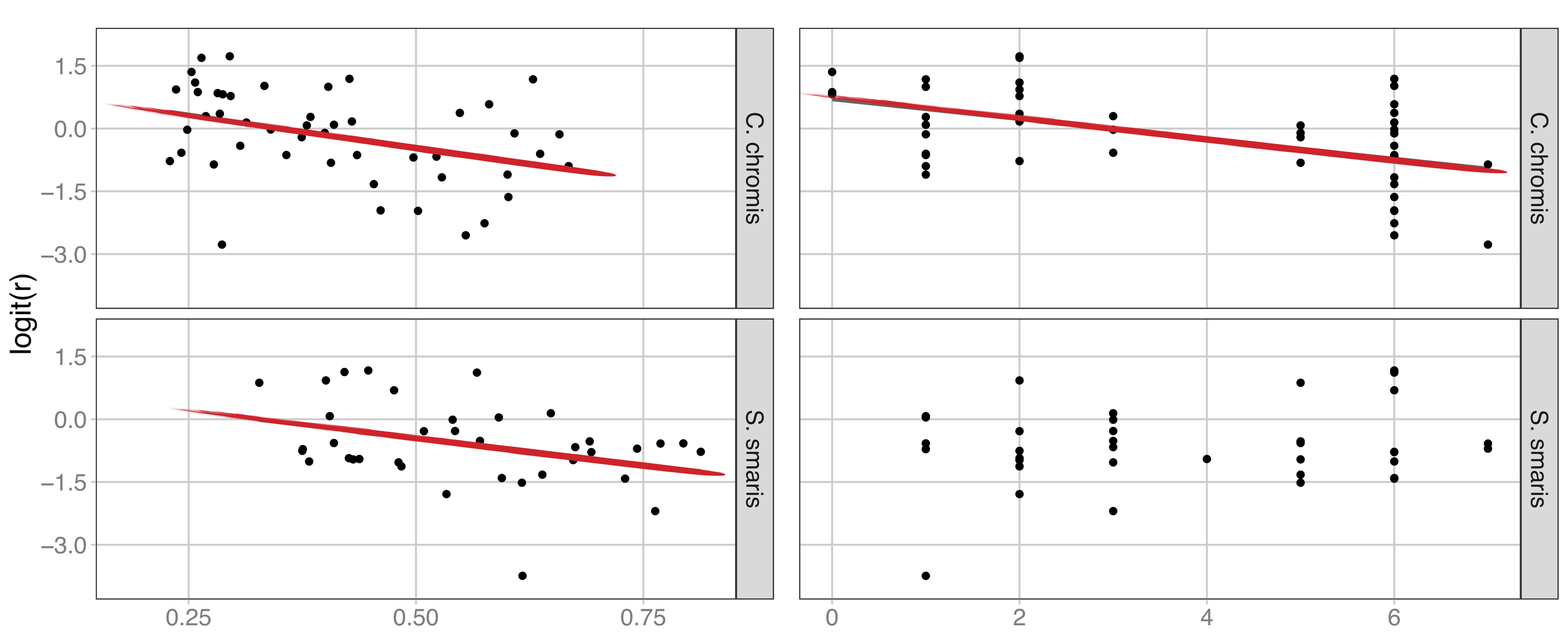


Fig 6. Regressions of directionality (Rayleigh's r) on solar index and cloud cover for *C. chromis* and *S. smaris*. Regression lines are drawn for significant correlations only. Directionality was strong in the morning and decreased linearly along the day. Directionality decreased with cloud cover for *C. chromis*.

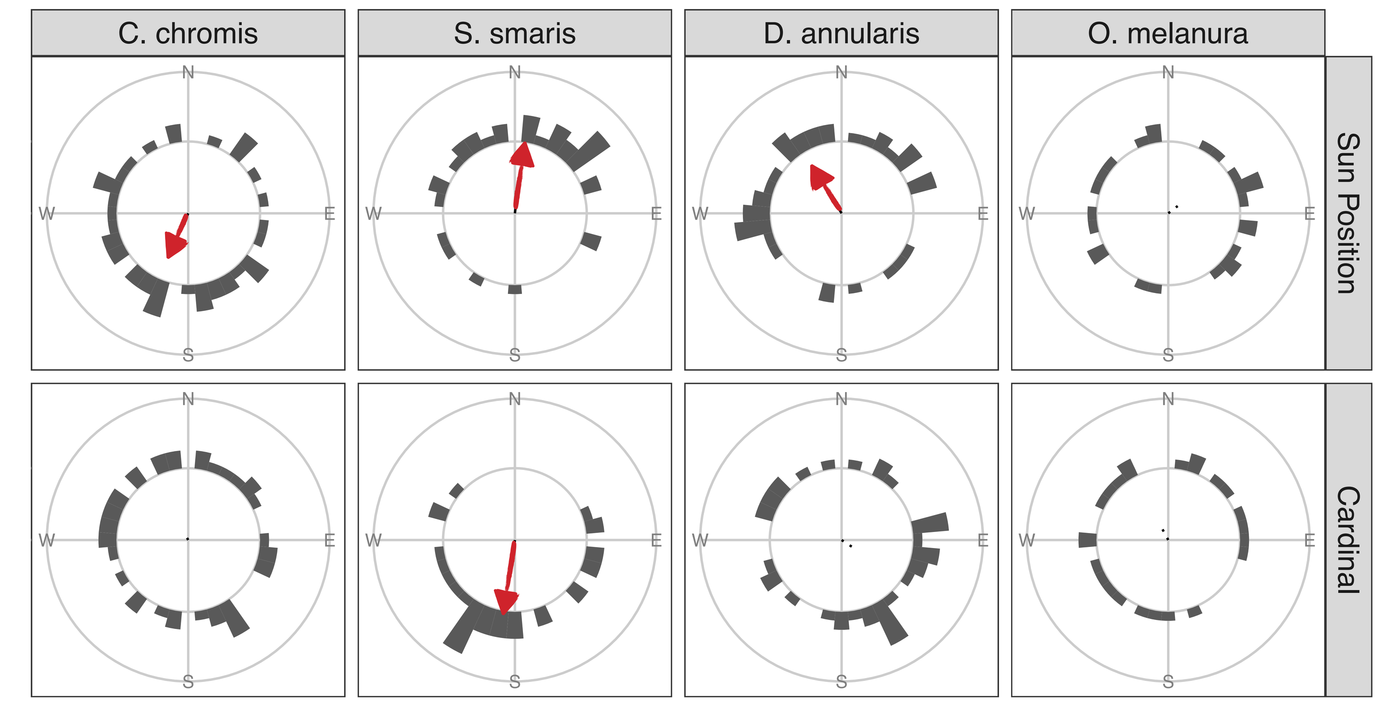


Fig 7. Orientation in cardinal reference and relative to the sun position. Each bar represents the bearing frequency among all 15-min runs. Mean bearings per-run are binned over 10°. The radius in the middle shows the mean direction of orientation and its length is proportional to the orientation precision (across-run Rayleigh's r). Significant orientation is indicated with the red arrows.

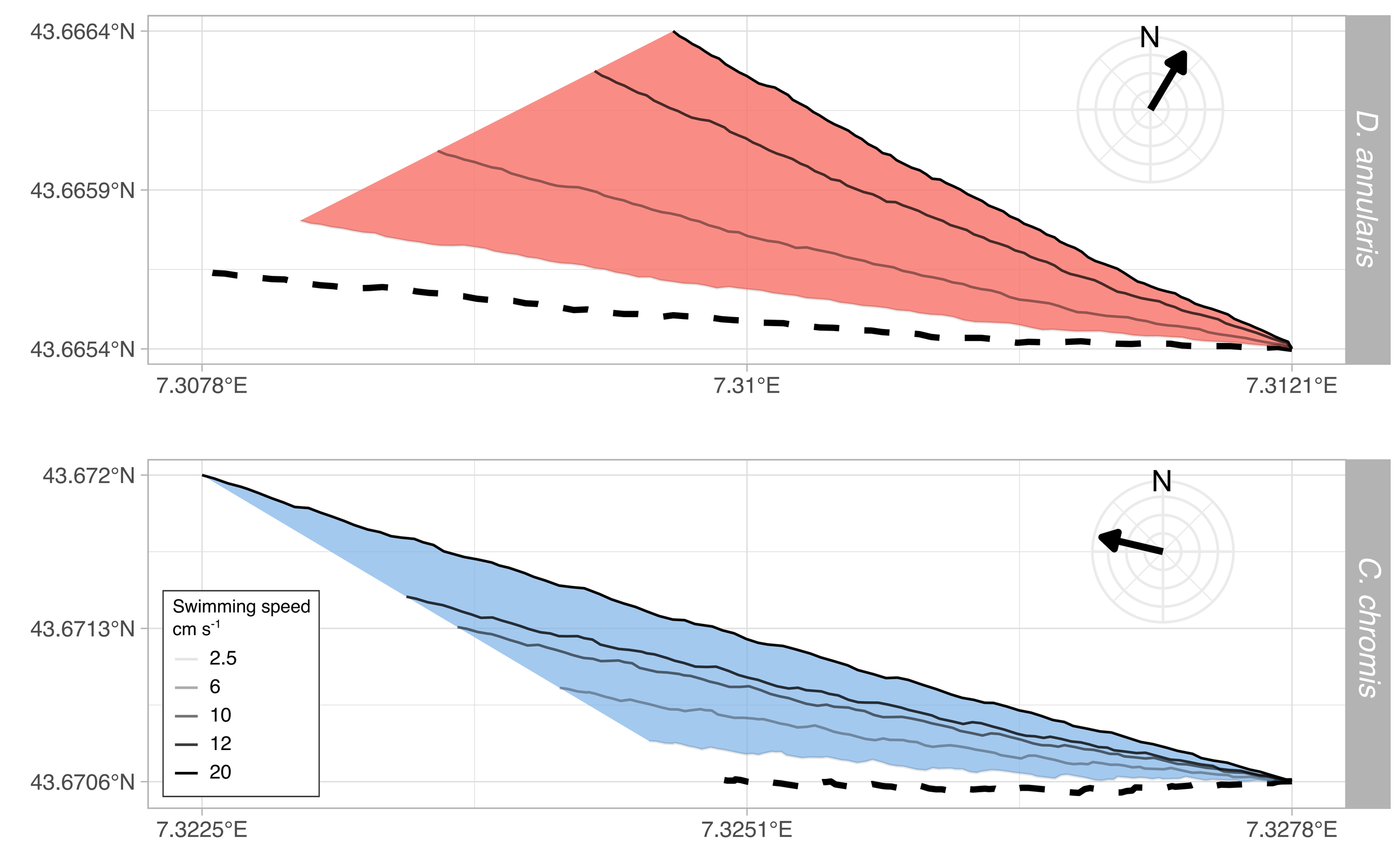


Fig 8. Example of expected displacement of two larvae from the passive trajectories of the DISC during their deployment. For each larva, the mean bearing was added to the trajectory of the DISC over the duration of the run (dashed line). These displacements highlights how larval orientation behavior may increase retention when the ocean currents advect the larva away (eg. *D. annularis*, top panel, 1/2Ucrit=2.5 to 12 cm s-1), or increase dispersal when swimming with the currents (eg. *C. chromis*, lower panel, 1/2Ucrit=2.5 to 20 cm s-1), compared to the passive dispersal (ie. the DISC trajectory during the deployment).

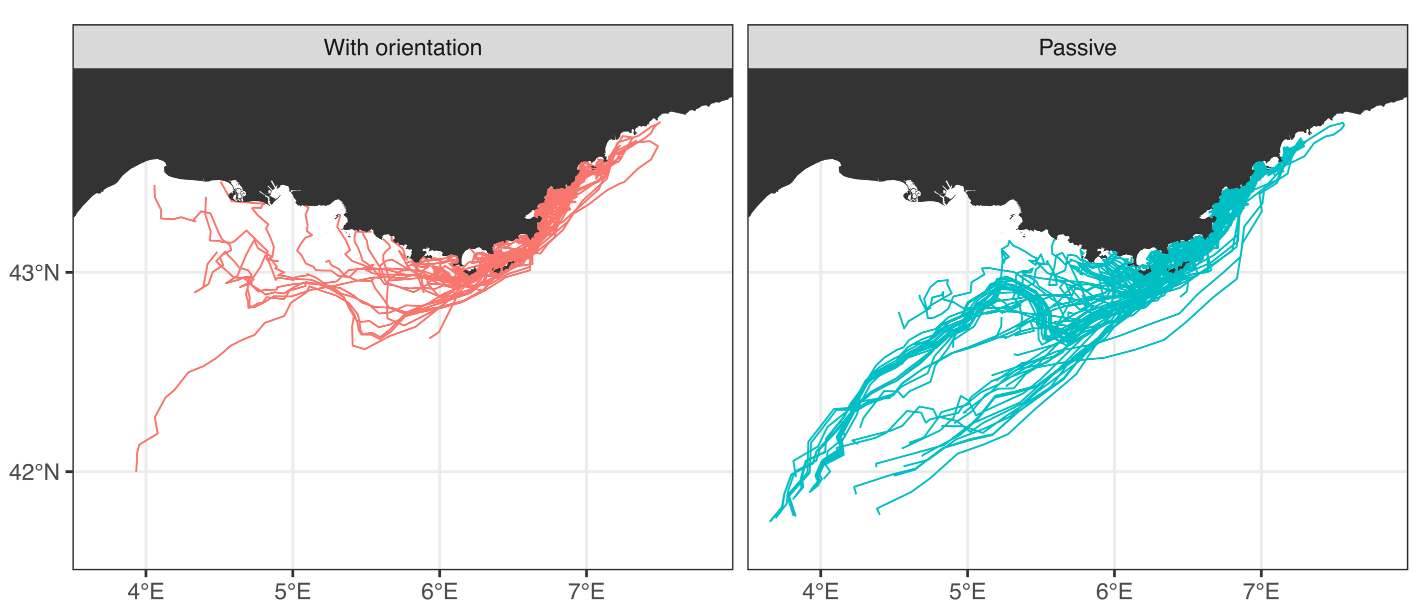
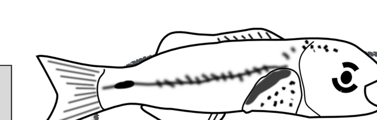


Fig 9. Changes in the trajectories with and without sun compass orientation, in Mediterranean fish larvae. Trajectories were computed with the Connectivity Modeling System (Paris et al. 2013) and the MARS3D ocean circulation model. Particles were tracked for 15 days. In the active simulation, virtual larvae were initially passive until flexion (approx. 7 d), then orientation behavior started until the competency phase (i.e. 15 d).



Take Home Messages

- The DISC is an efficient way to measure larval fish orientation *in situ*;
- Mediterranean fish larvae responded preferentially to the sun position and intensity, over all other tested cues (ie. direction of the wind, the coast, the currents, and the cardinal direction);
- Still little is known on the orientation abilities of larval fish offshore;
- Considering this potential coastal-independent compass in dispersal studies is critical, as it drastically alters passive dispersal patterns over both short (Fig. 8) and longer time scales (Fig. 9).

References Faillettaz et al. 2015, Sun Compass Orientation, PLoS ONE; Paris et al. 2008, OFWNOR, 59th An. Meet. G. Carib. Fish. Inst; Paris et al., 2013, Connectivity Modeling System. Env. Model. & Softw. 42, 47–54; Mouritsen et al. 2013, PLoS ONE; Bottesch et al. 2016, Curr. Biol.