Orientation of Fish Larvae

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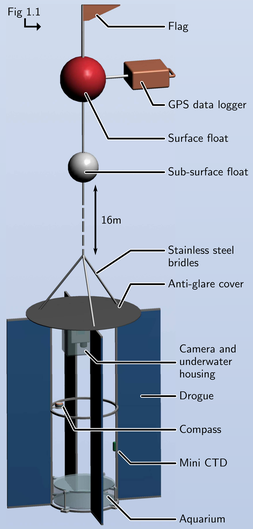
Abstract

While there is mounting evidence that larval coral reef fishes develop strong behavioral capabilities through ontogeny and at settlement, the influence of these capabilities on dispersal patterns depends on their ability to orient in the open ocean. A novel device was designed to detect and quantify the orientation behavior of larval fish while embedded in oceanic water masses were they have no apparent frame of reference. The Orientation With No Frame Of Reference (OWNFOR) system produces video clips of larvae swimming drifting aquarium. This in situsystem provides unbiased orientation data that are analyzed using Open Source Software (OSS). Early results suggest that (1) orientation vs non-orientation behavior can be detected, (2) two kinds of orientation behavior are distinguished using two approaches of Rayleigh's statistics, and (3) the choices of the shape of the drifting chamber and of statistical treatment diminish the impact of the enclosure of the larva on orientation results. This innovative observational technique is a critical phase to break into emerging questions in the field of larval ecology, providing major biological inputs to transport models and applicable to a large array of organisms with a pelagic larval stage.

BlueBidule Hardware

Fig 1.1



1. Why is orientation important for coral reef fish larvae?

- It has been shown that larvae develop strong swimming capabilities and vertical migration early on (Fisher et al 2000, Paris and Cowen 2004).
- Swimming abilities in the horizontal and vertical may have a significant impact on larval dispersal (Leis 2002).
- Swimming is important only if combined with orientation with respect to the reef (e.g. sensing the reef) and/or to current direction (e.g. avoiding advection away from the reef).

2. Innovative approach

- A device was developed to investigate in situ ontogenetic abilities of fish larvae to orient and respond to changes in their displacement within the currents, with no apparent frame of reference.
- It is mainly designed as a drifter equipped with a camera, an environmental sensing system, and a semi-enclosed circular chamber (Fig 1.1).
- Larval fish is/are placed in the chamber and filmed while the apparatus is deployed at sea (Fig 1.2).

Fig 1.2

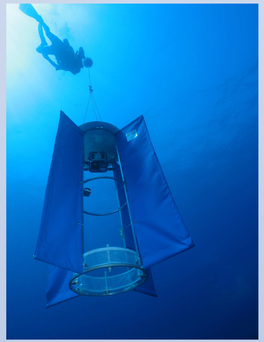
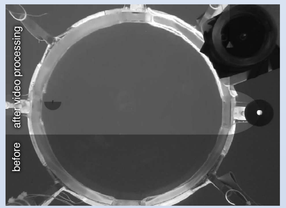
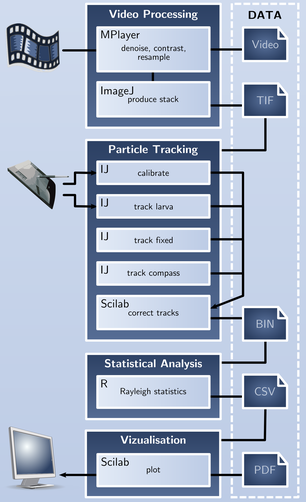


Fig 1.1: Schematic representation of the BlueBidule device.
Fig 1.2: Photography of the device underwater, off the Florida Keys.

BlueBidule Software

Fig 2.1





3. What is informative?

Orientation is associated with two characteristic behaviors (Fig 2.2):
(A) stoping when the larva encounters the chamber's boundary and swimming around the same position: larval position contains orientation information
(B) swimming along the boundary before swimming back in the direction toward which it orients: larval swimming direction contains orientation information

4. How to extract the trajectory and detect orientation?

STEP 1: Video processing
The video is large (30 frames/sec) and noisy:
- Image contrasting and denoising (Fig 2.1)
- Frame subsampling at 1 frame per second to produce manageable frame numbers and minimize error in estimating circular trajectories (Fig 2.3).

STEP 2: Tracking
- Manual calibration (e.g. size of the aquarium) and tracking the larva (i.e. click on it).
- Automatic tracking of the north of the compass and of the white dot fixed to the aquarium.
- Correction of the larval trajectory by these two reference tracks to obtain the true trajectory (i.e. corrected for cardinal reference and camera vibration).

STEP 3: Statistical analyses
Rayleigh statistics detect significant mean swimming direction and mean position bearings for independent angular data (H0=random bearings, H1=unimodal distribution of bearings).
Swimming directions are independent (Fig 2.4) but positions are not (Fig 2.4). Positions are bootstrapped by resampling randomly 3% of data which gives independence (Fig 2.4).

STEP 4: Visualization
Plots of raw data (trajectory), swimming direction vectors or significant bootstrapped positions are produced (Fig 3.2, 3.3, 3.4).

The analysis is conducted with Open Source Software.

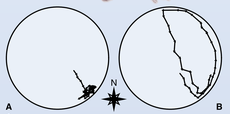


Fig 2.2

Fig 2.3

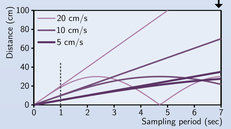
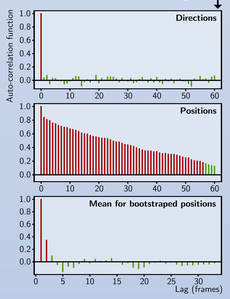


Fig 2.1: One frame of the video clip obtained from the device, before and after image enhancement.
Fig 2.2: Two characteristic behaviors (A and B) showing that the whole trajectory has to be extracted in order to obtain data on both positions and swimming directions.
Fig 2.3: The difference between real (straigth lines) and estimated (curves) distances travelled at different speeds on a circle of 15 cm of diameter leads to choose a resampling period of one second.
Fig 2.4: Autocorrelation values for directions (independent), positions (strongly dependant) and bootstraped positions (independent).

Fig 2.4



Test Results

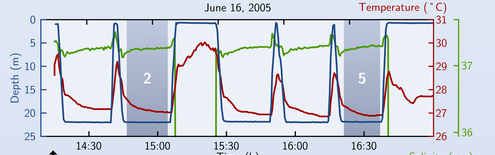


Fig 3.1

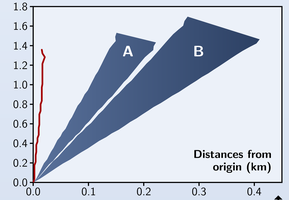
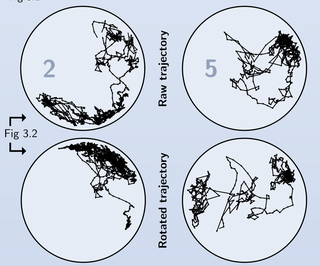


Fig 3.6

Fig 3.2



5. How to identify orienting and non-orienting larvae?

Two OWNFOR deployments (no. 2 and 5, Fig. 3.1) have been selected as exemples of trajectories of larvae within the circular chamber (Fig 3.2).
After correction for the rotation of the chamber (see STEP 2), the trajectory of larva no. 2 is more coherent compared to that of the raw data. Alternatively, the trajectory of larva no. 5 shows a more random pattern post-correction and is eliminated from further analyses. The swimming directions of larva no. 2 do not contain significant orientation information (Fig 3.3). However, the 500 tests on boostrapped position data were significant and distribution of the associated mean directions indicates that larva no. 2 orientates (Fig 3.4) at an angle with respect to the direction of the current in which the device is entrained (Fig 3.5).

Fig 3.3

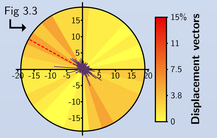


Fig 3.4

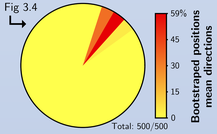
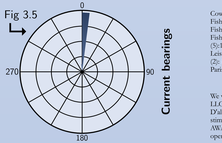


Fig 3.5



6. Influence of orientation behavior on larval trajectory

Based on observed range of orientation behavior (i.e. using critical speeds measured in the laboratory for larvae of the same family, Fisher et al. 2005), the trajectory of the orienting larva no. 2 departs quickly from the passive drift, with a zonal displacement ranging from 100-450 m in 20 minutes (or 7-32 km in 24 h). This deviation is even more remarkable since larva no. 2 orients with a small angular deviation of 30-70 degree from the strong northward flowing Gulf Stream (ca. 110 cm s-1). This has profound implications for modeling larval dispersal and patterns of connectivity in marine populations (see Cowen et al. 2006) and for conservation issues (Leis 2002).

Fig 3.1: Depth, salinity, and temperature profiles of five deployments of the OWNFOR device.
Fig 3.2: Uncorrected (top) and corrected (bottom) trajectories of two larvae, no. 2 and no. 5.
Fig 3.3: Displacement vectors of larva no. 2, plotted from the center of the aquarium. The red dashed line is mean direction. Pies are color-coded by the proportion of displacement vectors pointing in them.
Fig 3.4: Mean directions associated with the bootstrapped positions of the subsamples: significant subsamples (here all the 500 subsamples) are reprented in a pie chart color-coded by the proportion of mean directions pointing in them.
Fig 3.5: Rose diagram of the current bearings: most Gulf Stream current bearings point North.
Fig 3.6: Displacement of the device in km (red line) during a 20-minute deployment and simulated trajectory envelopes of larva n. 2 (damselfish) swimming at (A) half Ucrit (18 cm/s) and (B) Ucrit (36 cm/s). Half Ucrit is an estimation of the speed sustainable for 24h (Fisher and Bellwood, 2002).

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