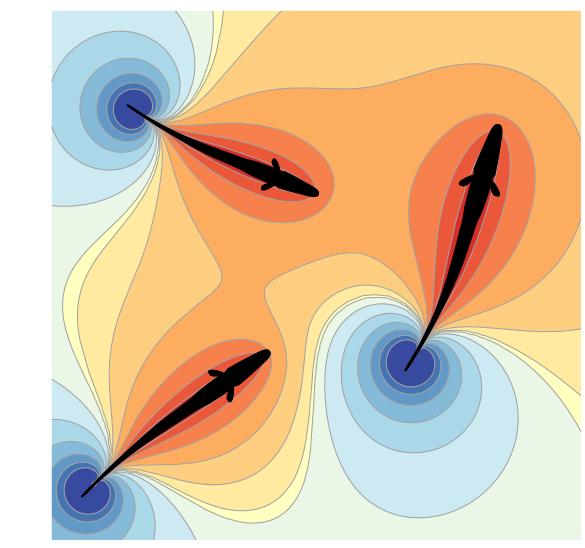


Complex frequency modulations in freely interacting electric fish, *Apteronotus leptorhynchus*, recorded in their natural habitat



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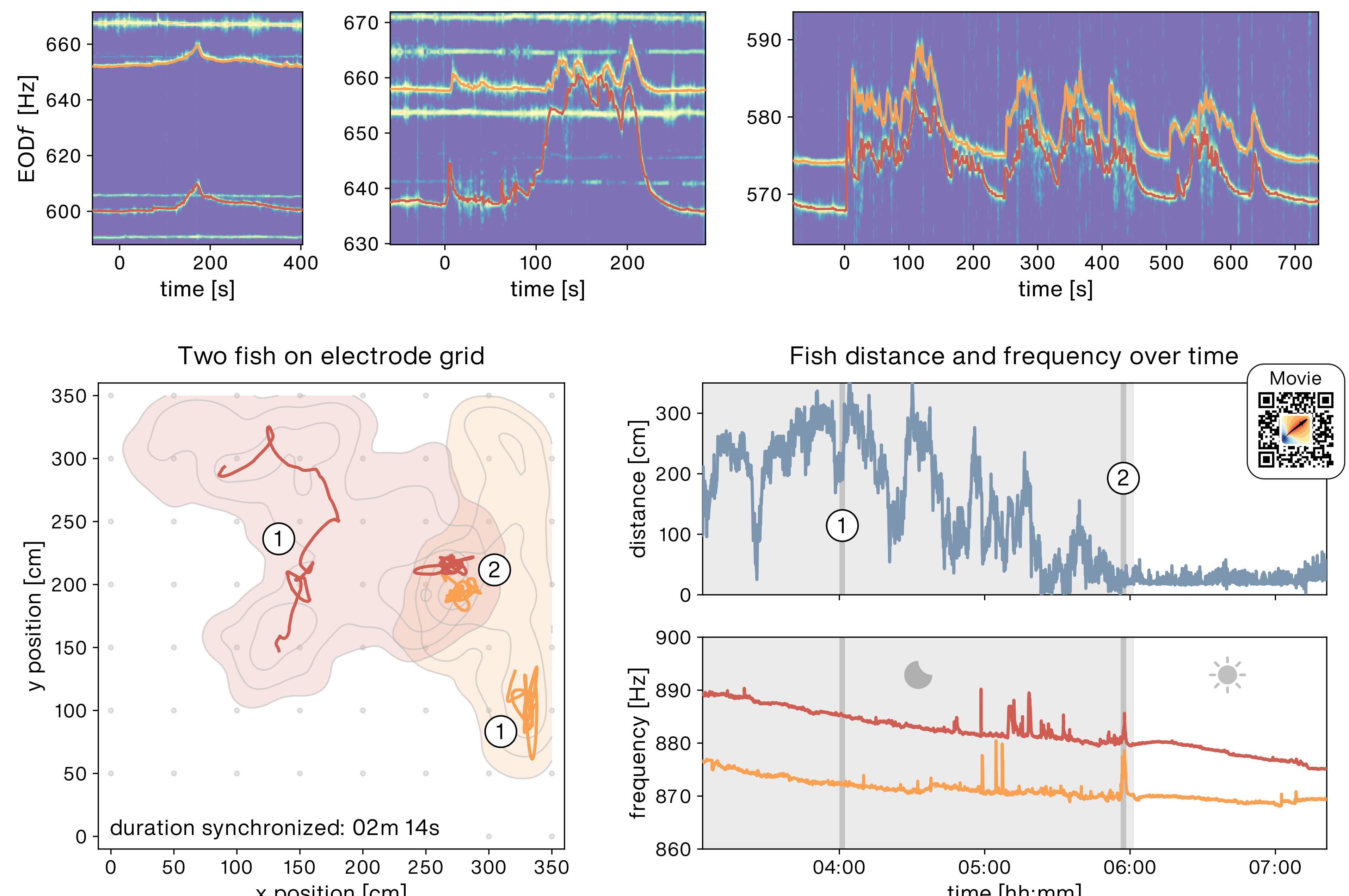
Introduction

Weakly electric fish use their electric organ discharge (EOD) for navigation, foraging and **communication**. Signals associated with communication (chirps and rises) are extensively studied and can be identified by their stereotyped EOD frequency ($EODf$) modulations. But signals that are not as stereotyped receive little attention. For a **natural population** of *A. leptorhynchus*, recorded using an array of 64 electrodes, we find **synchronous** $EODf$ modulations lasting many minutes. We designed a simple algorithm to detect synchronous modulations in two animals and analyzed their movements during frequency interactions.



Detected modulations

We found phases of synchrony up to 50 Hz in $\Delta EODf$ that lasted for over 10 minutes. Synchronous modulations ranged from clearly distinguishable and steep rises to smooth modulations with low $EODf$ increases.

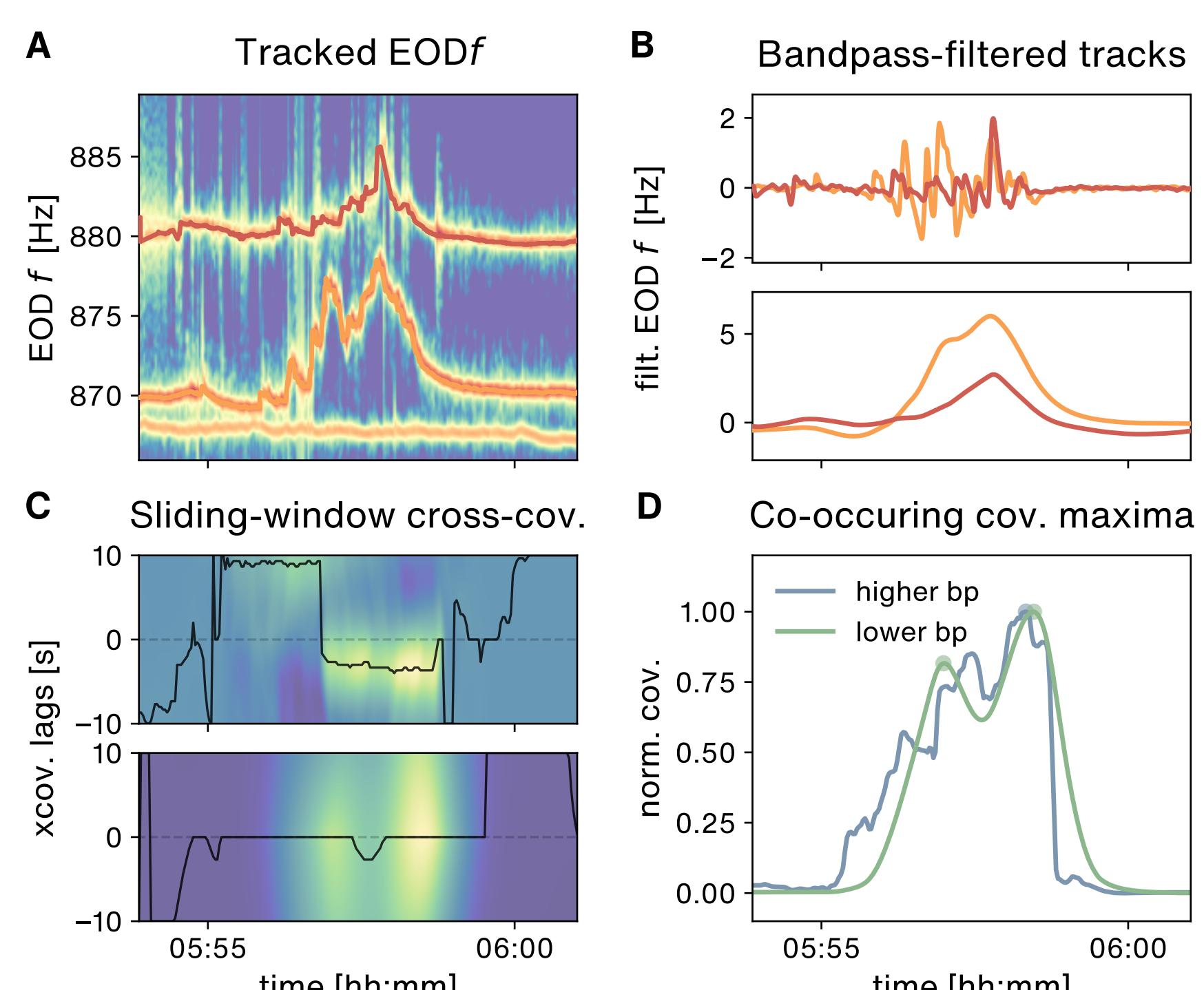


Event detection

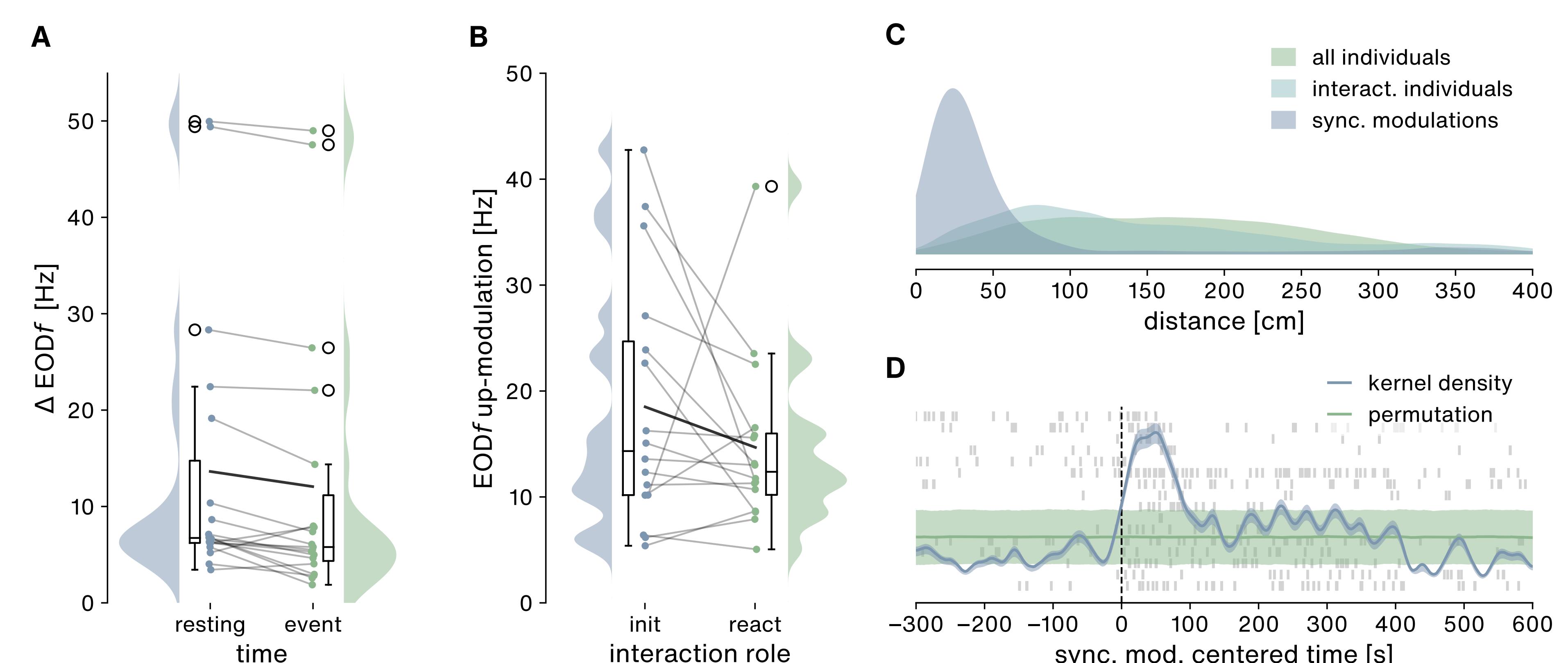
Detection of synchrony:

1. Extract pairwise $EODf$ tracks (A).
2. Bandpass-filter on two time scales (B).
3. **Sliding-window cross-covariances** of filtered track-pairs, extract maxima across all lags (black line, C).
4. Detect peaks in covariances. Simultaneously co-occurring covariance peaks are "events" (D).
5. Manual validation of detected synchronous modulations using a minimalist GUI.

Detection of physical interactions using proximity, velocity and relative angle of heading trajectories between fish.



Interactions at modulations



- $\Delta EODf$ does not appear to decrease during synchronous modulations (A).
- Individuals that rise their $EODf$ first appear to rise their frequency higher compared to reactors (B).
- Synchronized fish keep distances below 1 m (C) but distances over 3 m also occur (see **movie**).
- Spatial interactions increase **after** the start of a synchronous modulation (D).

Conclusion

- Our analysis is the first to indicate that *A. leptorhynchus* uses long, diffuse and synchronized $EODf$ signals to communicate in addition to chirps and rises.
- The recorded fish do not exhibit jamming avoidance behavior while close during synchronous modulations.
- Synchronous signals **initiate** spatio-temporal interactions.