E-Perceptive Biomass Monitoring Autonomous System Project: Main outcomes and Ongoing Work

1. Background and motivation

Insects have become a focus for concern about biodiversity loss and conservation, following studies showing strong signals of biomass, abundance, and diversity decline (e.g., Hallmann et al., 2017; Klink et al., 2020). Insects provide crucial ecosystem services (e.g., pollination, decomposition) on which human actives directly rely; further, they play a key role in food chains through their interaction with both upper and lower trophic levels. More recent studies have found that trends in insect biomass are better explained if complex, non-linear, relationships with the biophysical structure of their environments, including climatic conditions, land use change and habitat structure, are accounted for (e.g., Müller et al., 2023).

Methods to monitor the biophysical structure of ecosystems are constantly evolving, allowing for habitats to be monitored at increasingly fine spatiotemporal resolutions. Developments include advances in remote sensing (e.g., images from satellites and Unmanned Aerial Vehicles), AI-driven algorithms for data interpolation\interpretation, and super-resolution and advanced computer vision techniques for big-data classification. On the other side, techniques to monitor insects themselves still largely rely on manual sampling, with considerably lower spatiotemporal resolution and inconsistent standardization. This results in mismatches of quality, quantity, scale, and resolution, between data on the biophysical environments in which insects live, and the biotic data on the insect populations themselves.

Throughout the project, we addressed three main objectives:

(I) Development of an automated standardized system for flying insect biomass/abundance monitoring, with Near Real Time (NRT) capabilities.

(II) Initial testing of a close-range monitoring system, with NRT capabilities, able to capture images of insect instances for taxonomic classification.

(III) Use the biomass/abundance data produced with (I) to implement high-temporal resolution models of flying insect trends.

2. Objective I

The monitoring system is currently formed by a camera (mobile phone cameras) pointing towards a white target that covers the Field of View (FOV) of the camera (Fig 1). The distance between the camera and the target is known. Conceptually, the monitoring system records any moving instance passing in front of the camera.

Figure 1: Abundance/Biomass monitoring system. In the picture are visible the target (white panel) with Aruco codes for image geometry wrapping, the camera system and the solar energy battery system

From here two options are possible:

- Video recording with storage in local memory (e.g., phone memory or connected external drive) for post processing. In this case the only function of the monitoring system is to guarantee a standardized visual system, e.g., to be coupled with sticky traps. Refer to previous report for details.
- NRT data transmission of “flying” instances. We have developed an Android App (“Camera trApp”), designed for the system that extract only video frames with detected flying events through a dedicated ML model. The selected frames can be transmitted (through WiFi/data) in NRT to a server/cloud or store locally in the phone. In Figure 2 we schematize the Camera trApp functioning).

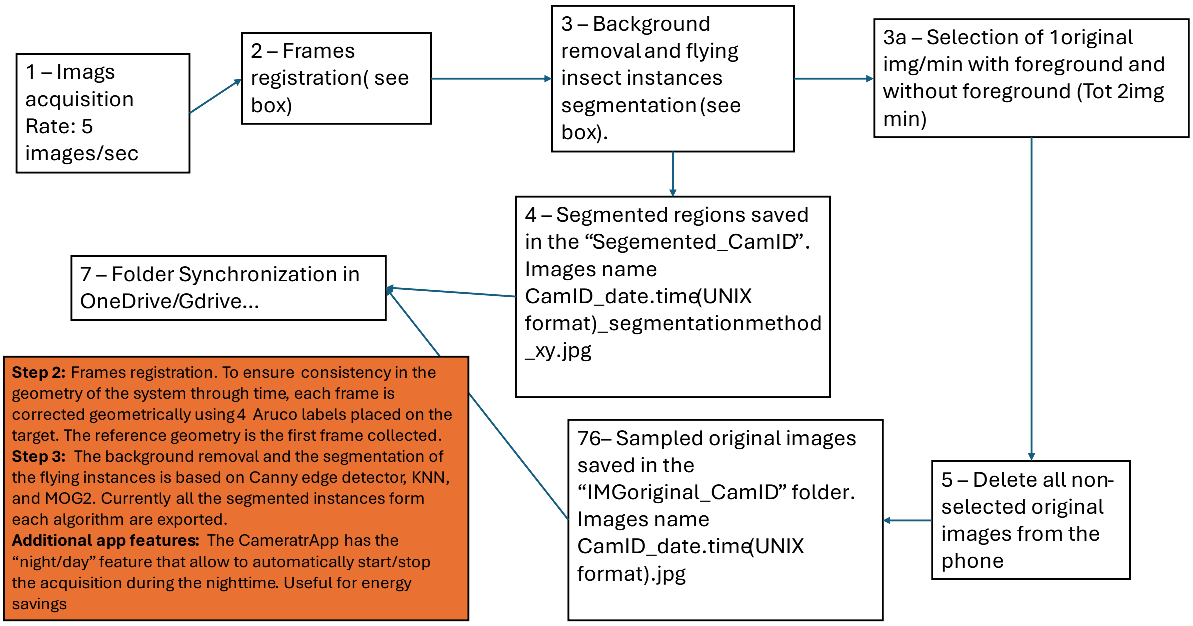

Figure 2: Schematization of the Camera trApp functionalities. In the orange box are reported some specification for the App.

2.1 Outcomes

- Dataset of flying insect biomass/abundance collected in the Cambridgeshire (see Objective III), used for method validation.
- Development of the Camera trApp system (now available as .apk file).

2.2 Possible research development

- The system has shown high accuracy to determine flying events (e.g., count the abundance). Nonetheless the estimation of the biomass has been developed only for the sticky traps, for which we assume all the insects entering the air space are attracted to and remain on the target surface to a known distance with the camera. In a context where no sticky trap is used (i.e., free flying insect in the air volume between camera and target) must be developed a system for the insect distance detection from the camera, being the distance a key parameter to determine the insect mass. This can be achieved through a hardware approach (e.g., development of a stereoscopic camera, lidar) or software (e.g., development of a dedicated monocular image depth estimation model).
- Camera trApp showed high performance to segment out flying object instances (insects, leaves, etc.). Currently the segmented instances must be processed remotely (e.g., with the model presented in the previous report) to differentiate insect from other events. This step could be implemented in the app.

3. Objective II

The camera system has been tested for close range detection, within a system studied to count flying insect emergence pattern from freshwater habitat. The monitoring system is composed of the phone (with the Camera trApp) with the main camera recording within a pipe, through a window. The pipe is installed on top of a pyramidal emergence trap; the emerging insect are forced through the pipe and recorded by the Camera trApp (see Objective I). On top of the pipe is possible to place a jar trap for preserving specimens for validation (Fig 3).

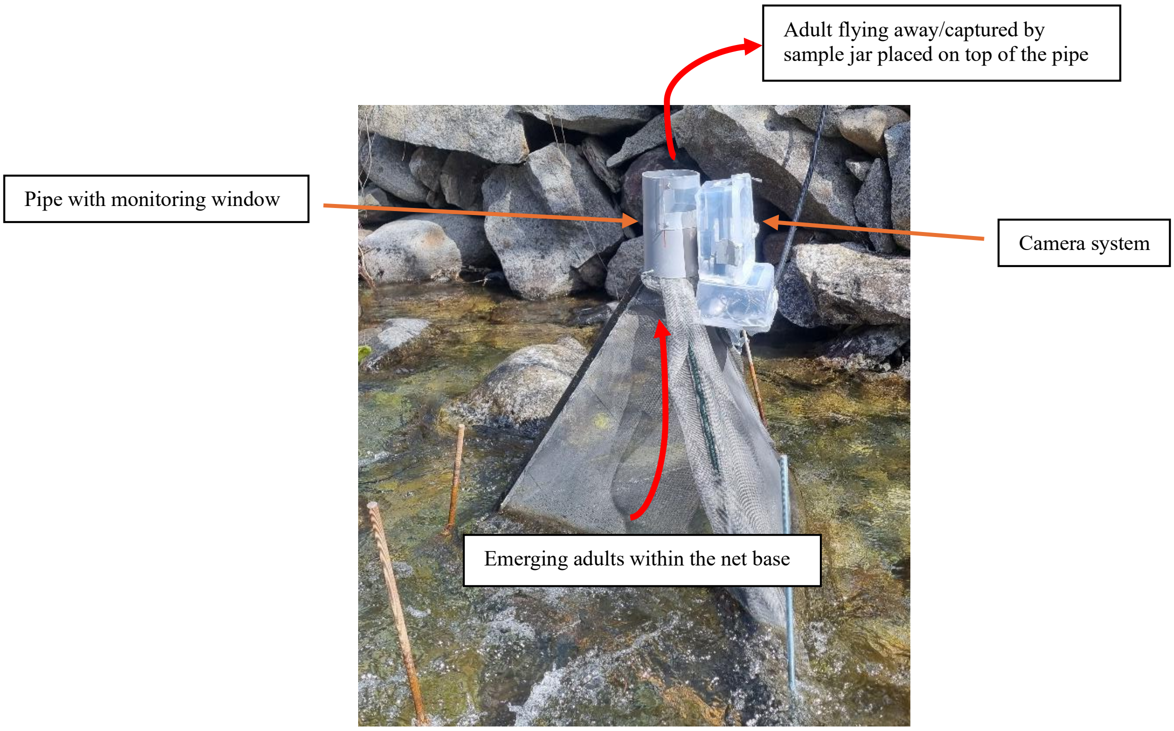

Figure 3: Close range camera mounted on an emergence trap. In the image are highlighted the main feature of the system.

3.1. Outcomes

- 4 close range traps have been tested in an alpine stream context for 4 months obtaining images as Fig 4. A database of emerging adults with 1h temporal resolution is available.
- 1 Possible paper.

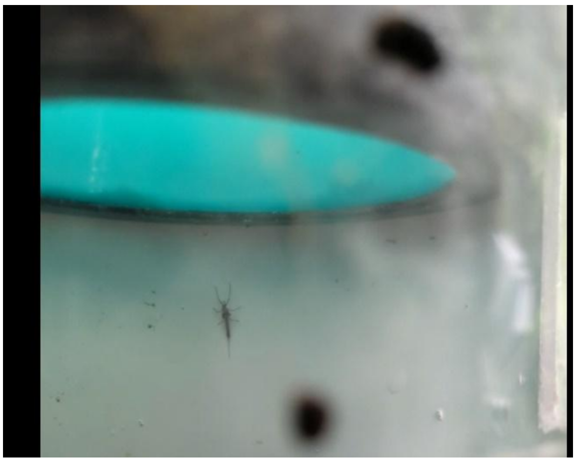

Figure 4: Example of emerging macroinvertebrate from the water captured by the camera in the pipe. The close-range position of the camera allows the system to capture more specimens details.

3.2 Possible research development

The system has shown high potential to track freshwater insect emergence to a high temporal resolution. Also, the estimation of the biomass through the equation reported

in the previous report has shown an accuracy of ±0.3 mg. Nonetheless the system is limited to the daylight acquisition; thus, the system could be improved with internal lightening of the pipe, but potential effects of emergence must be evaluated.
The images captured from the pipe (fig 4) can be explored to train or test existing models of taxonomic classification.

4. Objective III

The data collected from objective I in the Cambridgeshire (August 2023) has been analysed to test their use in a detailed lagged model, with the aim to predict trend of insects' abundance and biomass to an unprecedented temporal resolution (i.e., hourly) based on local meteorological conditions. The preliminary study can show the needs of high temporal resolution and potentially NRT insect data to improve existing models of insects' trends, including outbreaks (e.g., pest or disease monitoring).

4.1. Outcomes

A paper is being drafted. Submission deadline March 2025.