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Quantitatively scoring behavior from video-recorded, long-lasting fish trajectories

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Scoring animal behavior is increasingly needed for better understanding ecological processes. For example, behavior shapes harvesting likelihood, thus management of harvested resources should improve after accounting for behavior-driven processes. Automatic video-recording at controlled arenas is the most widespread method for scoring behavior. However, long term tracking animals while keeping identity is still an opened challenge. Here, we develop an ad-hoc algorithm for multi-tracking objects during days or even weeks, to fulfill the particular needs for a behavioral assay concerning a fish species targeted by recreational fishing. Specifically, we overcome the challenge of keeping fish identity in a context where they often disappeared from the camera when entering a shelter, the pixel size was low compared to the size of the arena and the lighting was constrained by the wellbeing of the fish. This work may contribute to better assess the behavioral features of fish in long-lasting lab conditions.

1. Introduction

Animals in wild populations are continuously at risk of being predated or harvested but some individuals have larger survival likelihood than others. For example, it is well known that hunting and fishing implies size-related selection (Matsumura et al. (2011); Uusi-Heikkilä et al. (2015)). Behavior-related selection has been reported as well (Biro and Sampson (2015); Ciuti et al. (2012); Diaz Pauli et al. (2015); Härkönen et al. (2016); Jørgensen and Holt (2013); Madden and Whiteside (2014)), so certain behavioral phenotypes are selected against (Alós et al. (2012), 2015); Diaz Pauli et al. (2015); Klefoth et al. (2013), Vainikka et al. (2016)). When the traits under selection are genetically heritable, the population may be driven to a harvest induced evolution (de Roos et al. (2006); Law (2007); (Philipp et al., 2015); Uusi-Heikkilä et al. (2015)), which implies a number of unintended and undesired outcomes that ultimately reduce yield (Matsumura et al. (2011); Mollet et al. (2016)).

However, such negative outcomes on population dynamics are expected only when selection gradients are consistent in time, that is, when a specific animal exhibits a given personality (i.e., it tends to behave in a similar way). The concept of animal personality (Dingemanse and Wolf (2010), 2013); Mittelbach et al. (2014)) is based in two patterns. First, the existence of between-individual differences in behavior that are consistently repeated at the long term (i.e., behavioral types) is often recognizable over the within-individual variability. Second, several behavioral traits are often correlated, shaping what it has been named as behavioral syndromes (Sih et al. (2004)), thus animal personality can be scored after knowing how the animal uses space in a number of contexts. Technological improvements have led to the widespread use of underwater devices for data collection, continuous monitoring and estimates of population parameters in the field (Williams et al. (2010); Aguzzi et al. (2013)). Indeed, cabled video observatories for the remote, long-term and high-frequency monitoring of fish and their environment have been used in coastal temperate areas (Aguzzi et al. (2013), 2015); Matabos et al. (2014)) to study behavioural response to environmental changes or human perturbations (Mecho et al. (2017)). Some studies in the field by using camera devices (e.g., (Alós et al. (2015); Mecho et al. (2017)) have already focused on the role of the behaviour in processes of

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artificial selection. Nevertheless, the study of behavioural types (or personality traits) by video recording in the field is still an open challenge since recognition at the individual level is required. Therefore, the actual limitation for a more widespread implementation of behavior focused management is seemingly not conceptual but technical: fish personality can be scored from their patterns of space use but only after a long-lasting observation time which includes individual fish recognition. In that context, video-recording fish in experimental conditions (i.e., tanks) is becoming a widespread method (Laskowski et al. (2016); Ozbilgin and Glass (2004); Papadakis et al. (2012)), in spite that some potential drawbacks (e.g., extrapolating the results to field conditions; (Niemelä and Dingemanse (2014); Závorka et al. (2015)). Alongside, unsupervised tracking on video-recorded is also increasingly required to better quantify long-term behavioral patterns, which in turn would allow scoring individuals in terms of animal personality. Hence, real-time tracking of video images should be preferred because rigorous statistical analysis of the behavioral patterns associated with movement involve not only long-lasting experiments but also unsupervised extraction of a number of space-use metrics (Papadakis et al. (2012)).

Unsupervised tracking of moving targets over a video sequence has been addressed from different fields (Burghardt et al. (2004); Dankert et al. (2009); de Chaumont et al. (2012); Kabra et al. (2012); Kühl and Burghardt (2013) and Trucco and Plakas (2006)). Even concerning the specific case of fish tracking, several techniques have been proposed (Delcourt et al. (2013); Dell et al. (2014) for a review)), enabling advances in behavioral studies. However, some challenges remain concerning long-lasting precise and accurate tracking of animals, especially when the experimental settings do not fit high standards. On one hand, how to preserve individuals identities throughout long time periods remains an opened question (Delcourt et al. (2013), but see Noldus et al. (2001) and Straw and Dickinson (2009)); on the other, specific experimental settings usually impose additional difficulties (e.g., arenas with uniform, white and artificial light conditions are generally used (Delcourt et al. (2006)).

Most tracking algorithms uses Kalman filters or particle filters for predicting positions of moving targets (Kalman et al. (1960); Nummiaro et al. (2003); Pinkiewicz et al. (2008)). Target detection is mainly based on detecting shape, color or finding blobs, which may be achieved via histograms analysis or attempting to maximize correlations between statistical models (Sattar and Dudek (2006)). Further, detection and tracking stages can be combined together in order to remove faulty detections (Fontaine et al. (2008); Spampinato et al. (2008); Xia et al. (2016); Pérez-Escudero et al. (2014); Chuang and Hwang (2016)). Recently, methods based on deep learning have been popularized. For example, the features of the fish head have been used to identify targets along frames (XU et al. (2017)). Similarly, (Qian et al. (2014)) combined Kalman filtering with the determinant of Hesssian. As deep learning methods have reveled as efficient alternatives for recognizing visual patterns, convolutional neural networks (CNN) has been implemented also (XU et al. (2017)). For instance, (Wang et al. (2016)) combined CNN with head fish identification, being able to track several individuals at the same time.

However, actual applications of these methods require highly standardized settings in terms of, for example, a well lightened and small scenario. This is not the case of the experiments that are currently conducted for assessing the links between behavior and vulnerability to fishing of a small-bodied marine fish (Alós et al. (2013)). This species, *Serranus scriba*, is one of the main targets of the recreational angler from Mallorca (Western Mediterranean) (Alós et al. (2013)). In this case, the experimental settings were particularly challenging. Individuals can appear and disappear from the scene because they were allowed to spend long periods of time in a shelter. However, fish identity must be preserved along days, which have been achieved by tagging the fish with colored marks. Provided that fish were submitted to several behavioral experiments, the tank must be continuously monitored during all the day-light period. Moreover, the experimental arena was very large in comparison to the sizes of colored tags, which imposed to deal with high resolution images in order to represent tags with enough number of pixels. Finally, the lightening conditions of the scenario must emulate those experienced by the fish at wild conditions; thus light had a strong blue component that difficult to discriminate fish from background and distorts colors. In addition, the lightening setting produces reflections and it was not uniform.

Even under those unfavorable experimental settings, we developed and described an ad-hoc algorithm for remote, long-term unsupervised-tracking of a number of fish moving in a tank. Moreover, the tracking algorithm has been coupled with proper statistical tools for extracting a number of metrics related with space use from fish trajectories, which will be used for analyzing of fish behavior and scoring fish personality.

2. Materials and methods

2.1. Model species

Serranus scriba is a simultaneous hermaphrodite serranid, widely distributed in the Mediterranean Sea. It is heavily exploited by the local recreational angling fishery (Alós et al. (2013)), which preferentially captures individuals with low reproductive investment and high adult body size (Alós et al. (2014)). Further, evidences of behavioural-related selection on exploration rates has been reported (Alós et al. (2012)).

2.2. Capture and tagging procedure

Fish were obtained from the wild by angling in coastal waters (from 5 up to 10 m depth) near the research experimental station (LIMIA), in Andratx Bay, on the SW coast of Mallorca, where experiments were conducted. Fish were double tagged with T-tags painted in different fluorescent colours (white (0), red (R) and green (G) tags were combined in pairs). Tagging was done by means of a hollow-needle tagging-gun according to (Dell (1968)). Length and weight measures were taken at the same time. Manipulation time did not exceed 1 min. Overall, transport, tagging and release into tank procedure took about 30 min. No mortality was observed neither during this procedure, nor during the experiment.

The experiments were conducted with adult fish (total body length 15.7 ± 1.9 cm; mean mass 53 ± 21.5 g; mean ± standard deviation). Fish were distributed in groups of 5 individuals of approximately the same size (0.6 individuals/m^2). Temperature water was the same as that of the sea (26.2 ± 0.6C; mean ± 1 standard deviation over all days of trials).

2.3. Scenario and experiment description

2.3.1. Scenario

The experimental tank, with dimensions 4 m × 2 m (length x with) and 30 cm water depth, was filled with sea-water and fitted with an open circuit filtering system. Due to the evidences that the behavioral performance of fish may be affected by environmental light conditions (e.g. Marchesan et al. (2005); Berdahl et al. (2013)); the experimental tank was illuminated emulating the natural light conditions of the habitat of the species, and at the same time covering the requirement of an homogeneous illumination in all the extension of the tank. The experimental light atmosphere was