Post-doctoral project

Adaptive monitoring for threshold passing control in population dynamics

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Application to the sterile insect technique optimization

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Scientific applicative context

The sterile insect technique consists in releasing large numbers of sterile males among a wild insect population, thereby instantaneously and drastically reducing mating success and therefore population size [Dyck et al., 2021]. This technique is expensive and its success relies on a very fine knowledge of the considered species dynamics in relation with its environment, and on an intense monitoring activity. To optimize this technique, release strategies must adapt to the current and projected spatial demography of the population. Feedback control strategies have been proposed for deterministic spatio-temporal models using estimations of the population current state [Agbo Bidi, 2024]. However controlled populations necessarily end up to exhibit highly stochastic behaviors, due to their small sizes. Our aim is to conceive optimized control and monitoring strategies to ensure that the population does not goes above some specific threshold, with high probability.

Project

Model. A first simple model can be that of the logistic birth and death process with immigration, with birth (resp. death) rate $b_n = \lambda n + \eta$ (resp. $d_n = \mu n + \alpha n(n-1)$), with positive parameters $\lambda, \mu, \eta, \alpha$. A more realistic model can include time dependent parameters, the use of compartmental (modeling life stage structured populations like insect species) or space structured processes. We will denote by $X_t \in \mathbb{R}_+^d$ the population state at time t, by $(\mathcal{F}_t, t \geq 0)$ the associated filtration, and by $g(X_t) \in \mathbb{R}_+$ the effective aimed to be maintained below a threshold H. For a standardized capture effort, a first observation model can be assumed to be of the form

$$Y_k \mid \mathcal{F}_{t_k} \sim \text{Poisson}\big(\lambda h(X_t, t_k - h \leq t \leq t_k)\big),$$

where $\lambda > 0$ is the capture probability and h is a fixed function of the population dynamics.

Expected results. A first axis will consist in determining an optimal monitoring strategy. On a fixed horizon T, we will aim at minimizing the mean number of trap readings, under explicit constraints of false alert, threshold passing detection, and delays after detection. After each observation, the date of the next reading we will be dynamically chosen, using the law of the population dynamics, and the risk to reach the threshold after this date. Adaptive strategies will

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be compared to the usual periodic traps readings, in terms of number of traps readings on this fixed horizon.
A second axis will concern the construction of a sequential decision algorithm. By denoting by $\mathcal{F}_t^{\text{obs}}$ the information brought by traps readings and known interventions up to time t, we will aim at computing

$$q_t = \mathbb{P}\Big(g(X_t) \geq H \mid \mathcal{F}_t^{\text{obs}}\Big).$$

For some tolerance parameter α that might depend on the species of interest and the associated threshold passing risk, a candidate rule will declare that the threshold has been reached if $q_t \geq 1 - \alpha$, that the population is below the threshold if $q_t \leq \alpha$, and that the information is insufficient otherwise. Sequential inference methods [Howard et al., 2021] offer an approach that can be adapted to the latent and evolving nature of the state. The study will combine Kolmogorov equations, filtering, and particle methods [Doucet et al., 2001], along with an analysis of approximation errors. In compartmental models, it will examine the conditions under which unobserved life stages can be inferred based solely on captureable individuals.

Application to the sterile insect technique

The developed methods will be evaluated on control scenarios, based on the one side on simulated data using realistic parameter values, and on the other side on real capture data of males, females, in a population submitted to the sterile insect technique. Collaborations will Hervé Bossin at Institut Louis Malardé (French Polynesia) will play a key role in this post-doctoral work.

Références

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