Appendix S1
Importance of non-pharmaceutical interventions in the COVID-19 vaccination era: a case study of Seychelles

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This Appendix provides details of the methodology for back-calculation of incidence and the simulation model.

We used a dynamic agent-based transmission model calibrated to reported cases in the Seychelles to examine the cause behind the recent surge in COVID-19 cases, and the role of vaccination and non-pharmaceutical interventions (NPIs) in the country. Timelines for non-pharmaceutical interventions adopted in the Seychelles are shown in Figure S1.

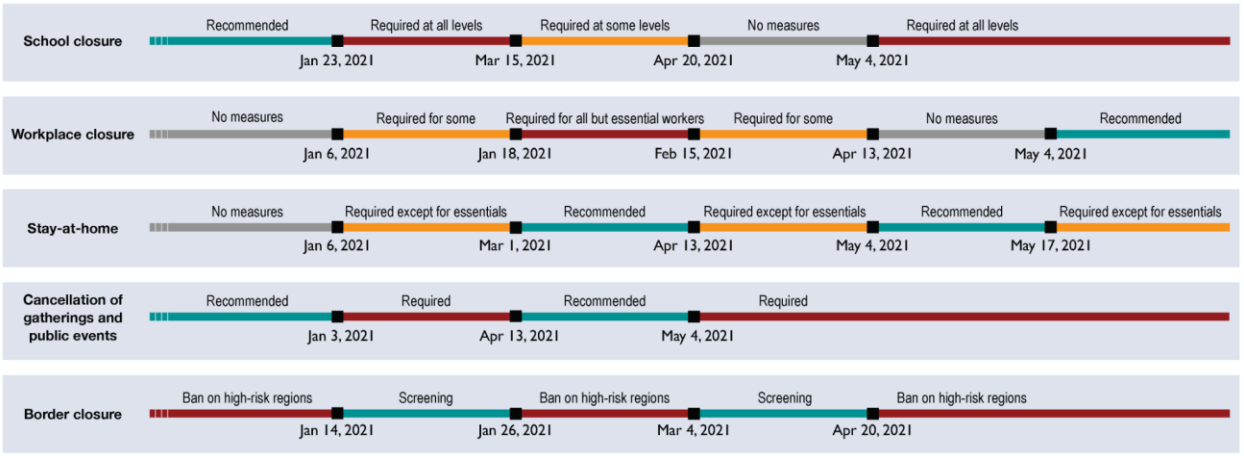

Figure S1. Timelines of non-pharmaceutical interventions implemented during the 2021 COVID-19 outbreak in the Seychelles. Vaccination against COVID-19 started on January 13, 2021.

Back-calculation of incidence

We used a Bayesian non-parametric approach to back-calculate the times series of infections based on the daily reported cases of COVID-19 in the Seychelles from October 21, 2020 to May 24, 2021.[1] Letting I_i represent the number of infections in the i^{th} time interval, the reported cases on day i, D_i, can satisfy the convolution equation: [2,3]

$$D_i = \sum_{j=1}^{i} I_j p_{i-j}$$

where p_{i-j} is the probability that the time between infection and identification is $i-j$. Considering the incubation period as a proxy for time from infection to identification, p_{i-j} can be

directly calculated from the incubation period distribution. Here we make a simplifying assumption that the distribution of the incubation period does not change over time.

We employed a Bayesian approach to estimate posterior densities of the expected incidence of infections in time i in a random walk simulation process. The observed number of infections at time i (the calendar day i) was modelled by a nonhomogeneous Poisson process: $I_i \sim \mathrm{Poisson}(\lambda_i)$ where prior distributions for the λ_i were uninformative given by $\lambda_1 = \mathrm{Uniform}(0, 10^3)$, and $\lambda_i \sim \mathrm{Normal}(\lambda_{i-1}, \sigma^2)$, for $i \geq 1$ in the truncated distribution for $\lambda_i > 0$. The standard deviation, σ, was set to 10 for our analyses to maintain some variation. Back calculation was implemented in a Bayesian Markov Chain Monte Carlo (MCMC) setting using Nimble, with the R statistical environment acting as the front end. MCMC simulations were run in 5 independent chains, each consisting of 25,000 iterations, with a burn-in period of 10,000 iterations and a thinning factor of 10. To assess convergence, we inspected the trace plots and applied the Gelman-Rubin convergence test by computing the potential scale reduction factors (PSRF) of posterior densities. Figure S1 shows the simulation results for the cumulative incidence of infection with the 95% credible interval.

Agent-based modelling

We fitted an agent-based model of COVID-19 transmission to incidence derived from back-calculation from October 21, 2021, to January 6, 2021. In this period, there were no school or workplace closures, and non-pharmaceutical interventions for stay-at-home, and cancelation of gatherings remained mainly at the “Recommended” level. Border restrictions included a ban on high-risk regions for International travelers (Figure S1). We determined disease transmissibility by fitting the model to incidence data during this period while accounting for mask-wearing and recommended measures to reduce contact patterns to 80% of the pre-pandemic behaviour. The model simulated scenarios of COVID-19 incidence without vaccination, and when vaccination was implemented on January 13, 2021.

Model structure

We adopted our previous agent-based model [4] with the natural history of COVID-19, including epidemiological classes for susceptible; latently infected (not yet infectious); asymptomatic (and infectious); pre-symptomatic (and infectious); symptomatic (and infectious) with either mild or severe illness; recovered; and dead. The model population was stratified into six age groups of 0-4, 5-19, 20-49, 50-64, 65-79, and 80+ years based on demographics of the Seychelles.[5] Daily contacts between individuals were sampled from a negative-binomial distribution parameterized using an empirically-determined age-specific contact network.[6,7]

Disease dynamics

We parameterized the transmissibility of asymptomatic, mild symptomatic, and severe symptomatic stages to be 26%, 44%, and 89% relative to the pre-symptomatic stage.[8–10] The incubation period was sampled from a log-Normal distribution [LogN(shape: 1.434, scale: 0.661)] with a mean of 5.2 days.[11] For those who developed symptomatic disease, the pre-symptomatic stage was sampled from a Gamma distribution [Gamma(shape: 1.058, scale: 2.174)] with a mean of 2.3 days.[9,12] The infectious period following the onset of symptoms was

sampled from a Gamma distribution [Gamma(shape: 2.768, scale: 1.1563)] with a mean of 3.2 days.[9,13] Those who did not develop symptomatic disease remained asymptomatic until recovery, with an infectious period that was also sampled from a Gamma distribution [Gamma(shape: 5, scale: 1)] with a mean of 5 days.[13,14] We assumed that recovery from infection conferred immunity against reinfection for at least one year. We also assumed that all symptomatic cases who were not hospitalized self-isolated within 24 hours of symptom onset, and reduced their number of daily contacts by an average of 75%.

Vaccination

We implemented a two-dose vaccination campaign from January 13, 2021, and used the weekly average of vaccine doses distributed since the start of vaccination to simulate the vaccination scenario.[1] Two different vaccines used in the Seychelles included Sinopharm (with a 21-day between doses interval) and AstraZeneca (with a 28-day between doses interval). Among fully vaccinated individuals by May 8, 2021, 57% had received Sinopharm vaccines and 43% were vaccinated with AstraZeneca shots.[15] Since data on efficacy of Sinopharm vaccines are limited, we used efficacy data of AstraZeneca vaccines as the best-case scenario, and considered vaccine efficacy of 76.0%, (95% CI: 59.0% - 86.0%) and 81.5%, (95% CI: 67.9% - 89.4%) against symptomatic disease 14 days after first and second doses, respectively; 100% against severe disease 14 days after the first dose; and 51.9%, (95% CI: 42.0% - 60.1%) and 77.3% (95% CI: 65.4% - 85.0%) against infection 14 days after the first and second doses, respectively.[16–21]

Model implementation

We simulated the model with a population of 98000 individuals, assuming no pre-existing immunity. Results were generated by averaging 500 independent Monte-Carlo realizations in each scenario, and credible intervals (CrI) were generated using the bias-corrected and accelerated bootstrap method (with 500 replications). The model was implemented in Julia, which is an open-source, high-performance, dynamic programming language. The simulation codes are available at: https://github.com/thomasvilches/Seychelles

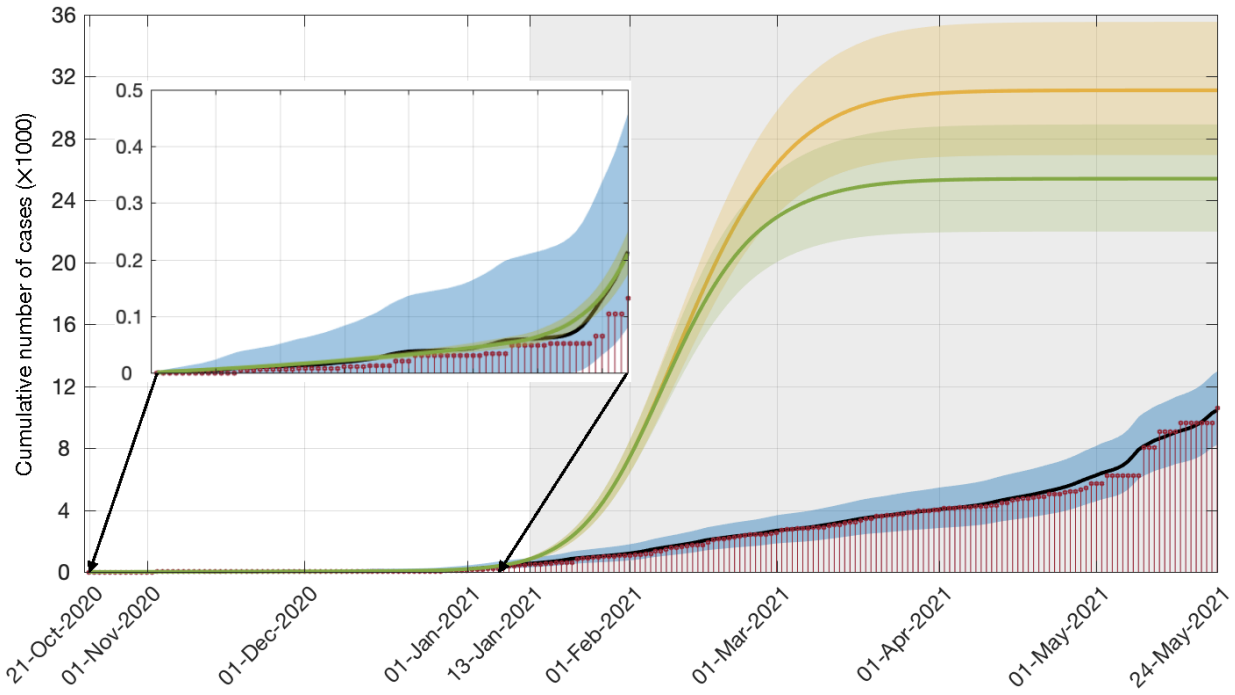

Figure S2. The cumulative mean of posterior distributions for infections (black) back-calculated by fitting the convolution equation to daily reported cases (red). The 95% credible interval is represented by a blue shaded area. Simulated outbreaks using the agent-based model (fitted to cumulative infections till January 6, 2021) are shown for the cumulative number of infections without vaccination (orange curve), and with a two-dose vaccine series (green curve). Shaded orange and green areas represent the 95% credible intervals of simulated outbreaks. Grey area represents the vaccination era.

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