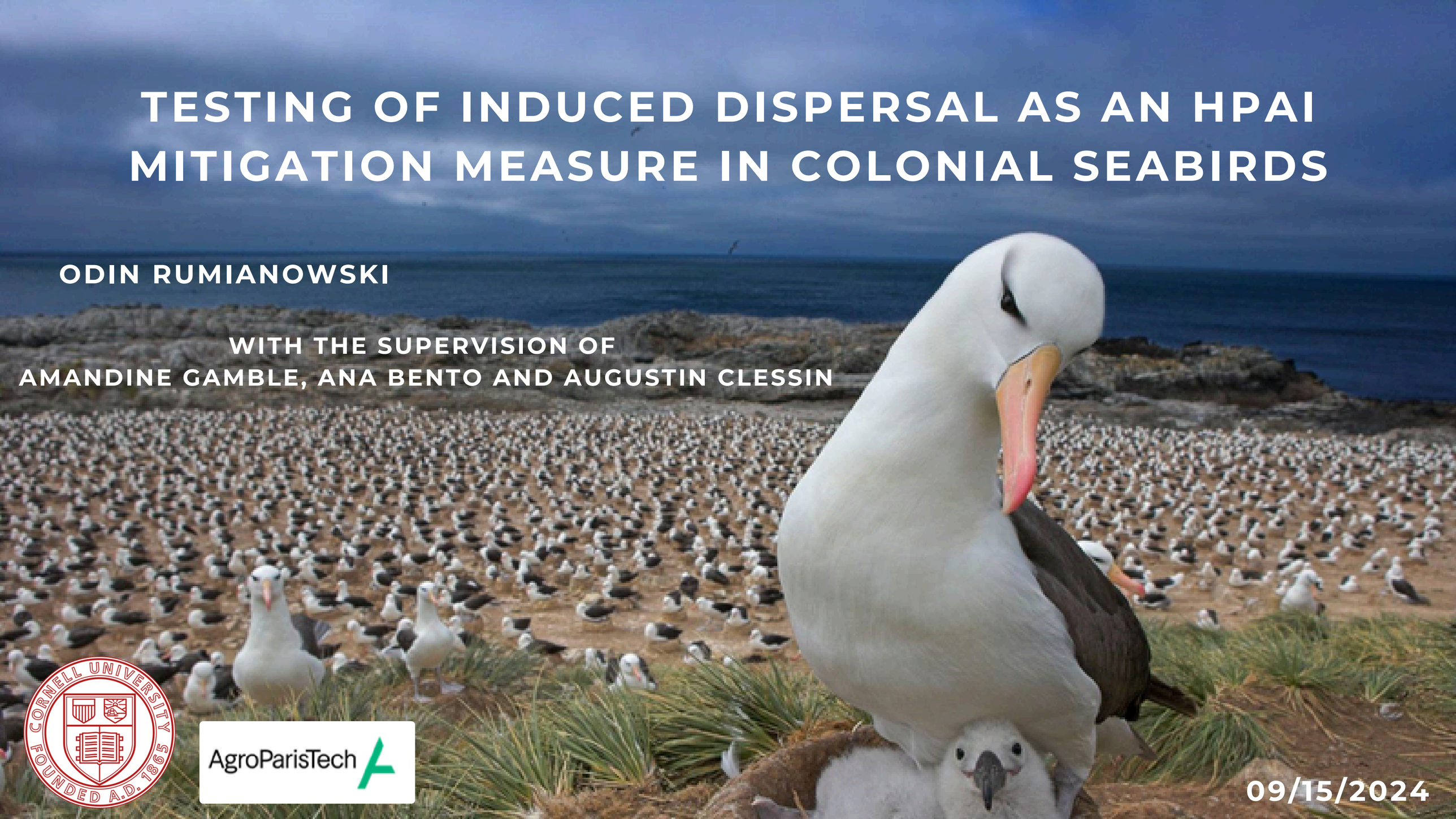
TESTING OF INDUCED DISPERSAL AS AN HPAI MITIGATION MEASURE IN COLONIAL SEABIRDS

ODIN RUMIANOWSKI

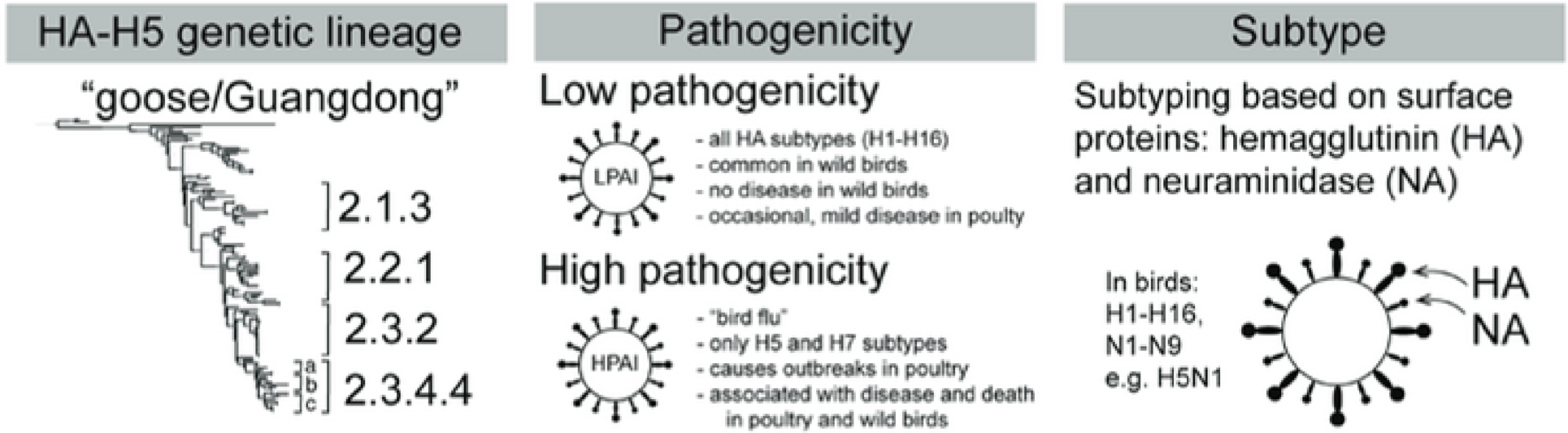
WITH THE SUPERVISION OF
AMANDINE GAMBLE, ANA BENTO AND AUGUSTIN CLESSIN



09/15/2024

CONTEXT

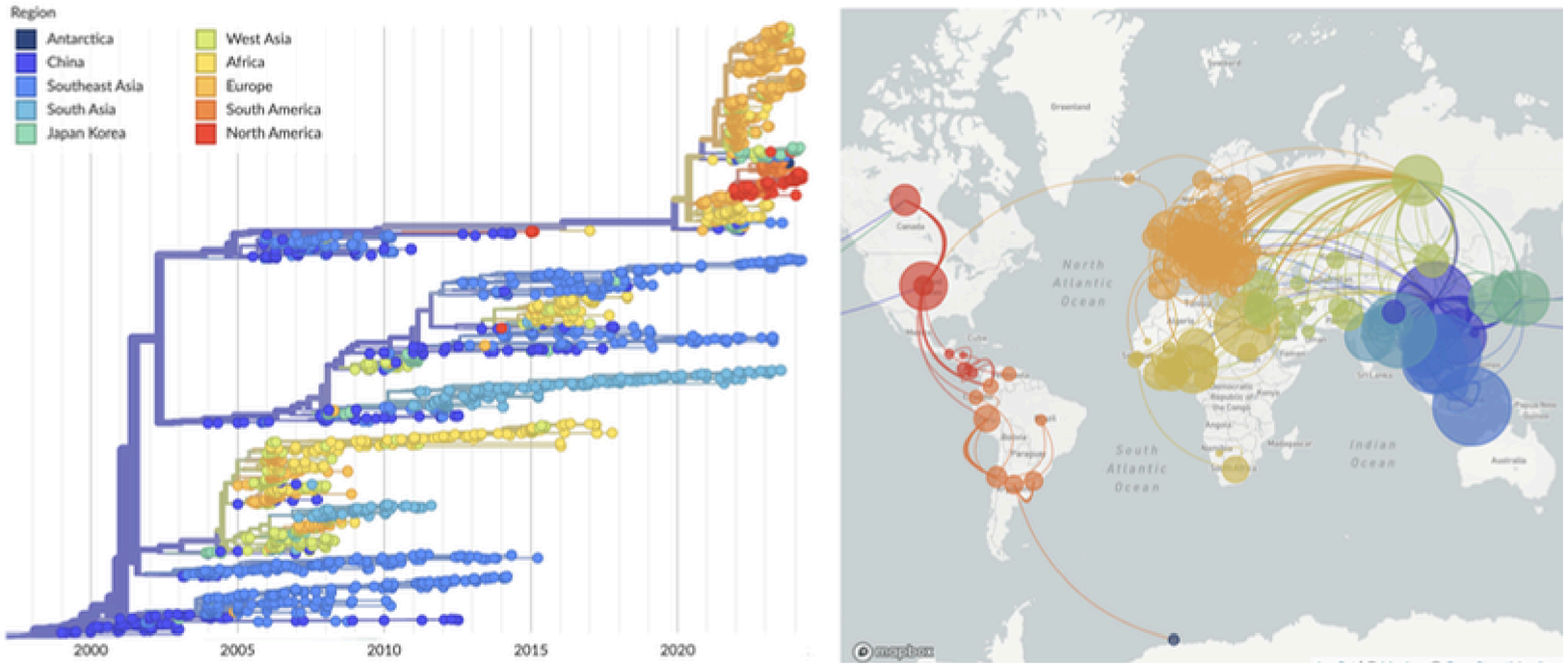
- **What is HPAI (Highly Pathogenic Avian Influenza)?**
  - Waterbirds are well known reservoirs for LPAI
  - LPAI viruses are very common in the temperate Northern Hemisphere
  - HPAI viruses cause substantial mortality when they spill over from poultry into wild waterbirds



AVIAN INFLUENZA CLASSIFICATION
(WILLE & WALDENSTRÖM 2023)

CONTEXT

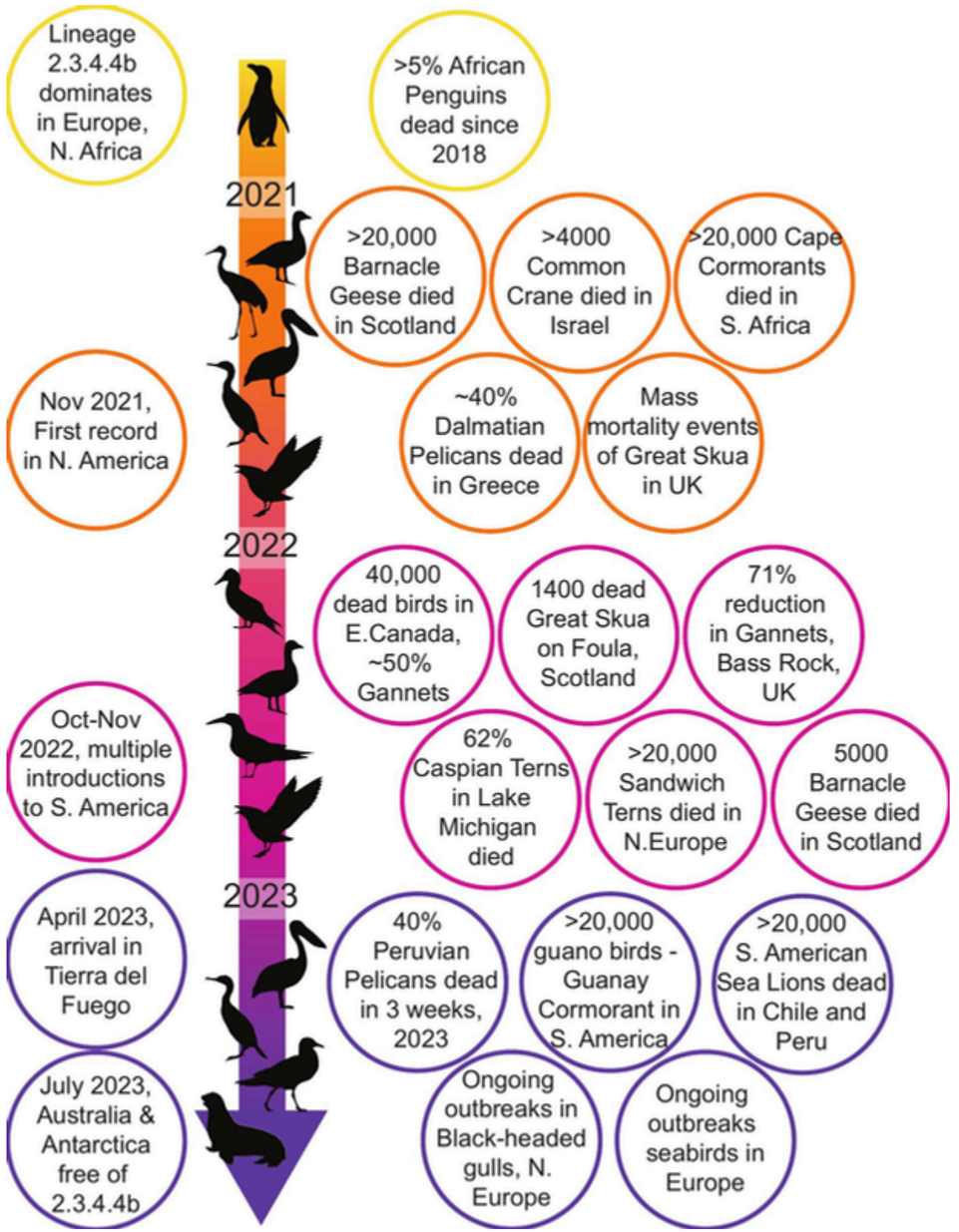
- **Current outbreak:**
  - HPAI panzootic commenced in 2021 following a genetic change in the virus (2.3.4.4b clade)
  - Change in the length of time of high activity
  - Spread to all continents within 2 years
  - Diversity of wild birds affected



BROADER CONTEXT OF H5N1 EVOLUTION AND SPREAD.
AVAILABLE AS NEXTSTRAIN.ORG/AVIAN-FLU/H5N1/HA/ALL-TIME.

CONTEXT

- **Impact on wild population:**
  - Mass mortality events in wild waterbirds
  - In March 2023, 320 bird species belonging to 21 orders have been affected
  - Unprecedented mass mortality in mammals (e.g. American Sea lions)



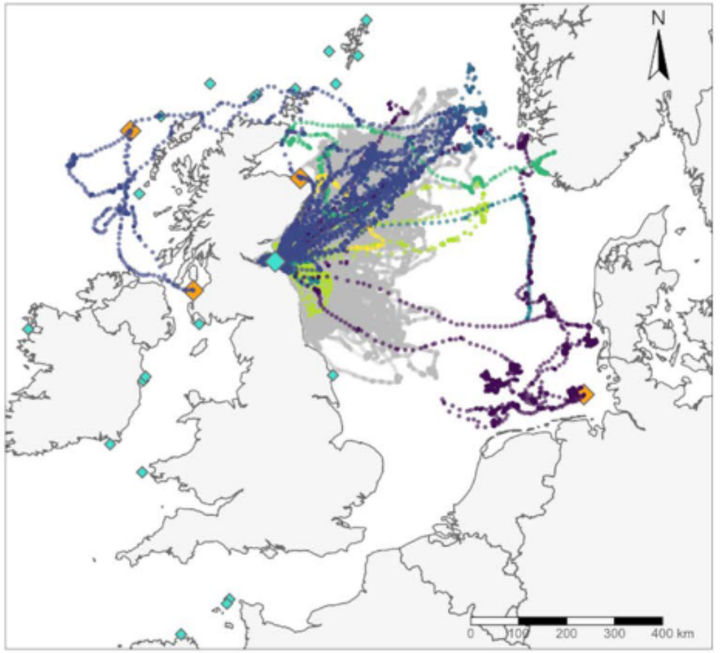
NOTABLE MASS MORTALITY EVENTS IN WATERBIRDS DUE TO 2.3.4.4B
(WILLE & WALDENSTRÖM 2023)

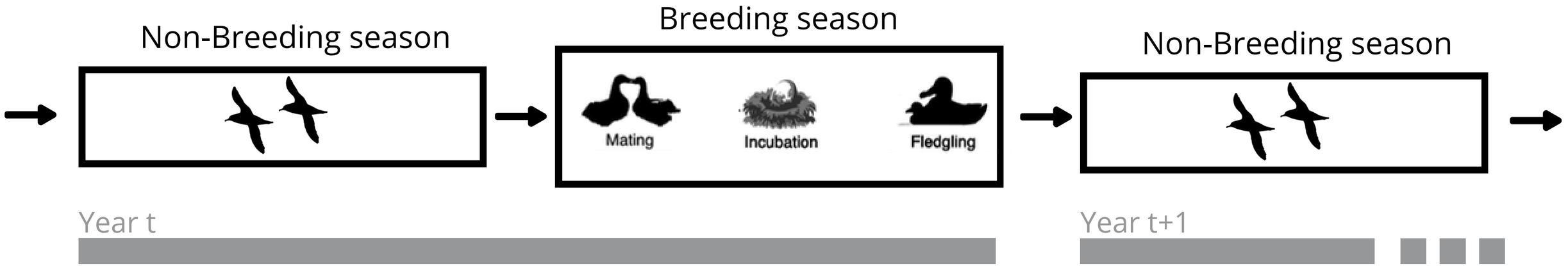
CONTEXT

- **Control Strategies:**
  - Management in poultry relies on biosafety measures and mass culling
  - Vaccination in wild populations:
    - Complicated to implement on a large scale
    - Unreactive measure - need to anticipate at least 2 weeks before the outbreak
    - A potential solution for small, endangered population e.g. Californian Condor

CONTEXT

- **Life cycle of seabirds:**
  - Reproduction life cycles over one or two years
  - A non-breeding period mainly at sea
  - A breeding period with terrestrial periods on colonies
  - Nests in dense colonies, where infectious contacts are favoured

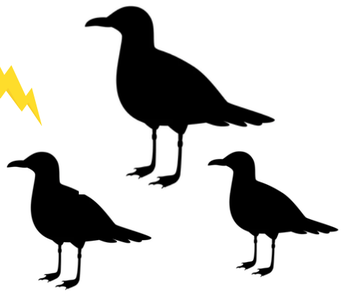




INDUCED DISPERSAL AS AN HPAI MITIGATION MEASURE ?

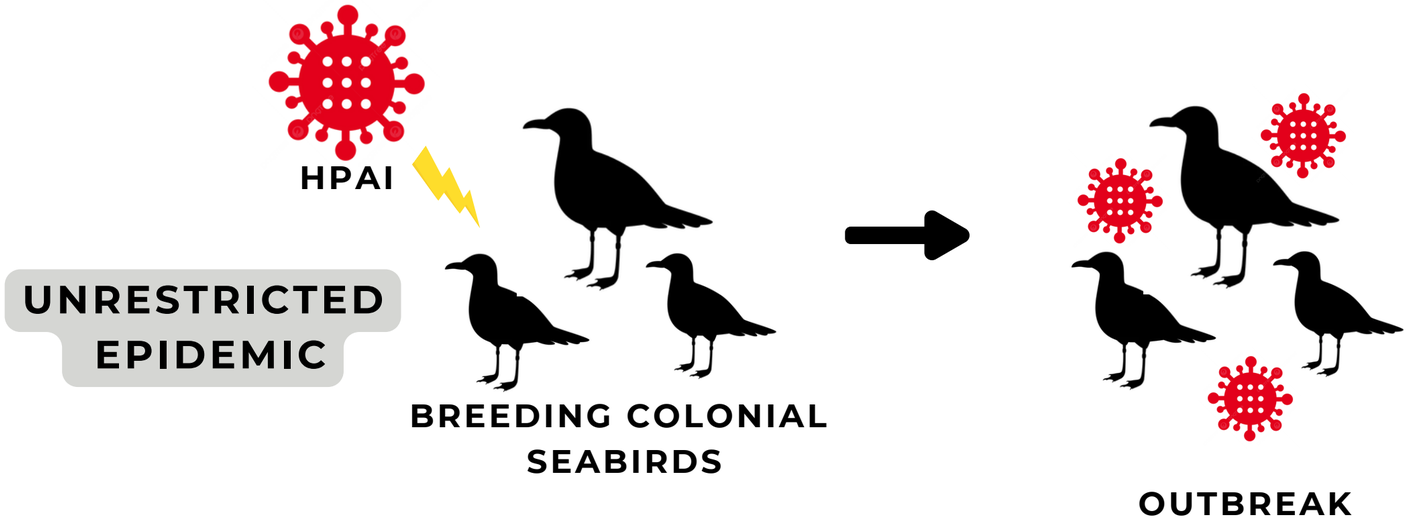
CONTEXT

UNRESTRICTED EPIDEMIC

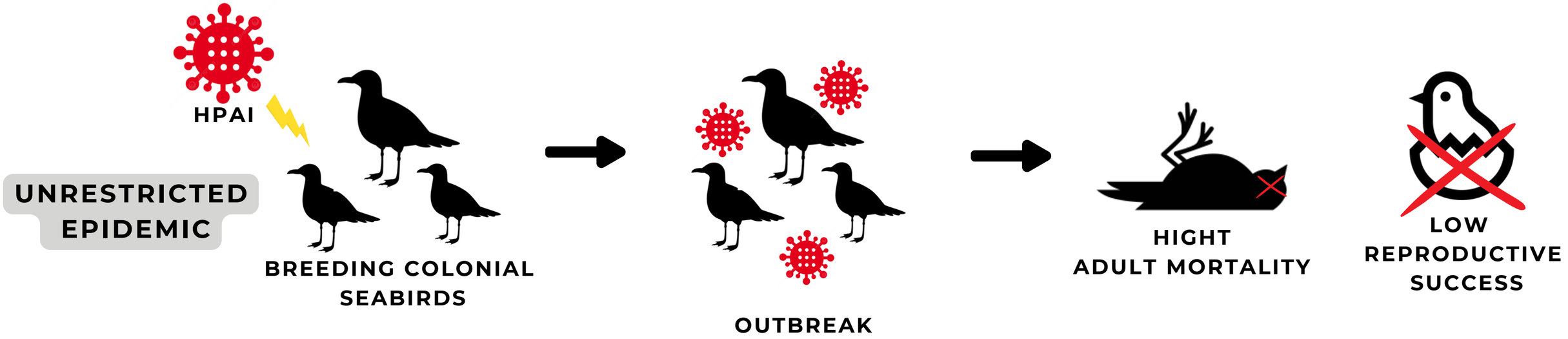


BREEDING COLONIAL SEABIRDS

CONTEXT

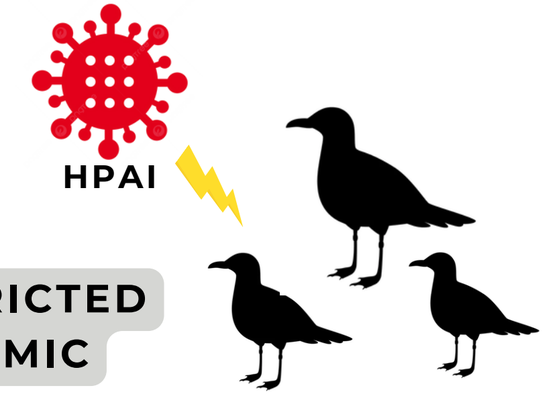

HPAI
UNRESTRICTED EPIDEMIC
BREEDING COLONIAL SEABIRDS
OUTBREAK

CONTEXT

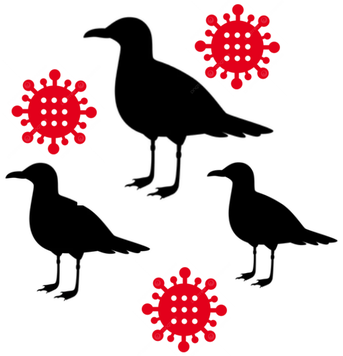

HPAI
UNRESTRICTED EPIDEMIC
BREEDING COLONIAL SEABIRDS
OUTBREAK
HIGHT ADULT MORTALITY
LOW REPRODUCTIVE SUCCESS

CONTEXT

UNRESTRICTED EPIDEMIC



BREEDING COLONIAL SEABIRDS

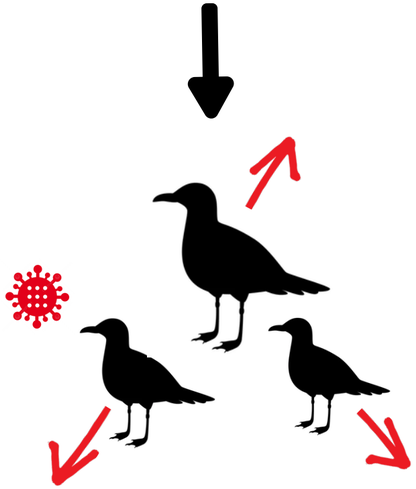


OUTBREAK

HIGHT ADULT MORTALITY

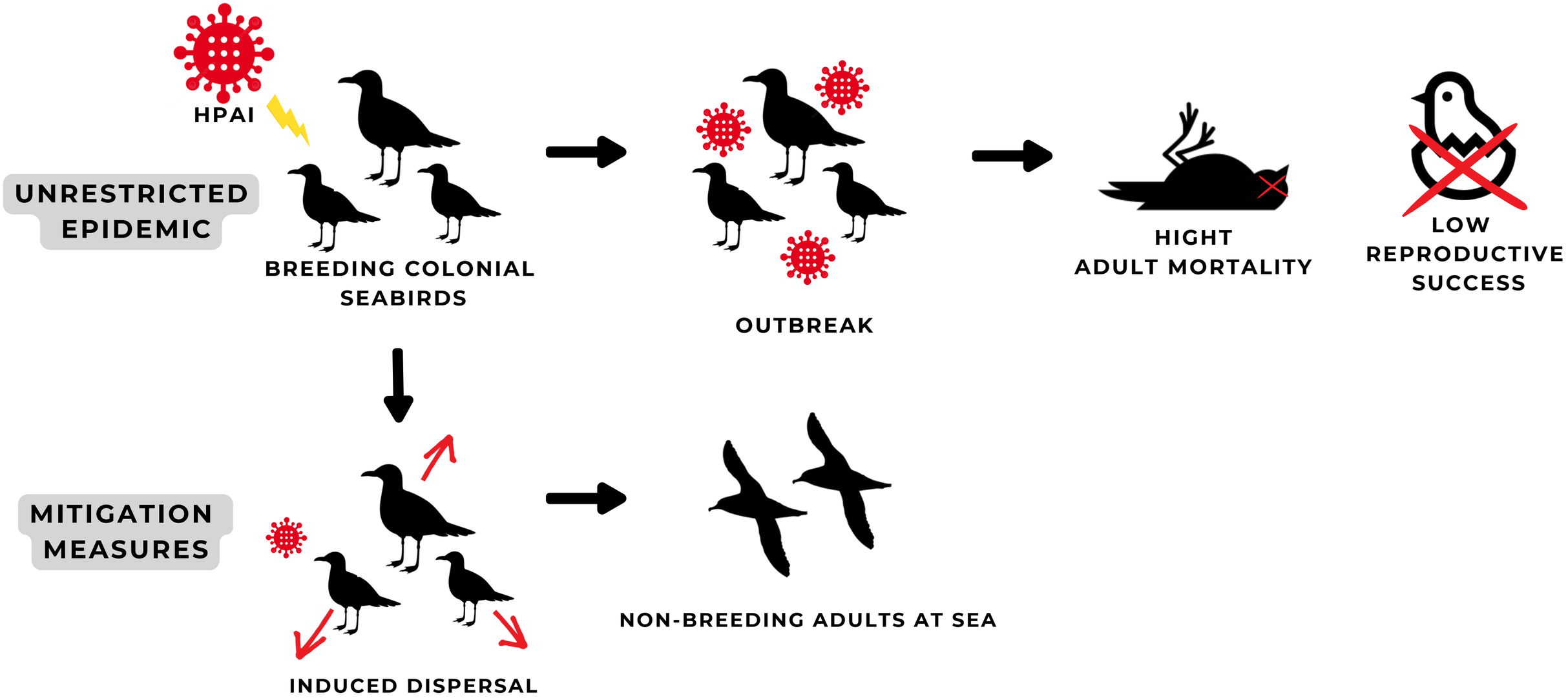
LOW REPRODUCTIVE SUCCESS

MITIGATION MEASURES



INDUCED DISPERSAL

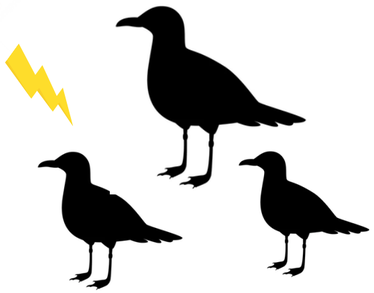
CONTEXT


HPAI
UNRESTRICTED EPIDEMIC
BREEDING COLONIAL SEABIRDS
OUTBREAK
HIGHT ADULT MORTALITY
LOW REPRODUCTIVE SUCCESS
MITIGATION MEASURES
INDUCED DISPERSAL
NON-BREEDING ADULTS AT SEA

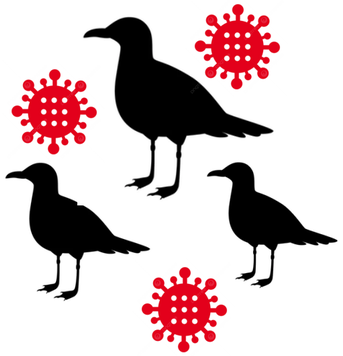
CONTEXT

UNRESTRICTED EPIDEMIC

HPAI



BREEDING COLONIAL SEABIRDS

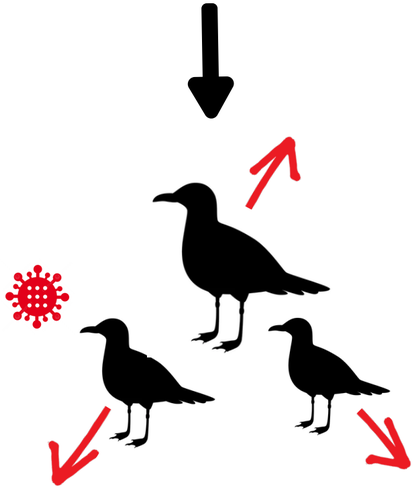


OUTBREAK

HIGHT ADULT MORTALITY

LOW REPRODUCTIVE SUCCESS

MITIGATION MEASURES



INDUCED DISPERSAL

NON-BREEDING ADULTS AT SEA

LOW ADULT MORTALITY

NO REPRODUCTIVE SUCCESS

OBJECTIVES

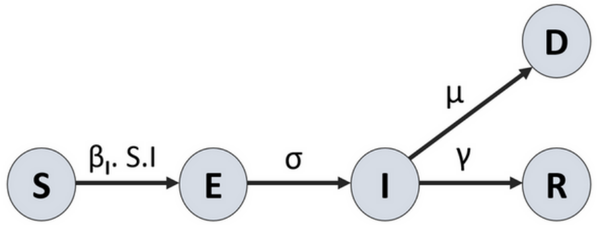
Induced dispersal to “dodge HPAI outbreaks :

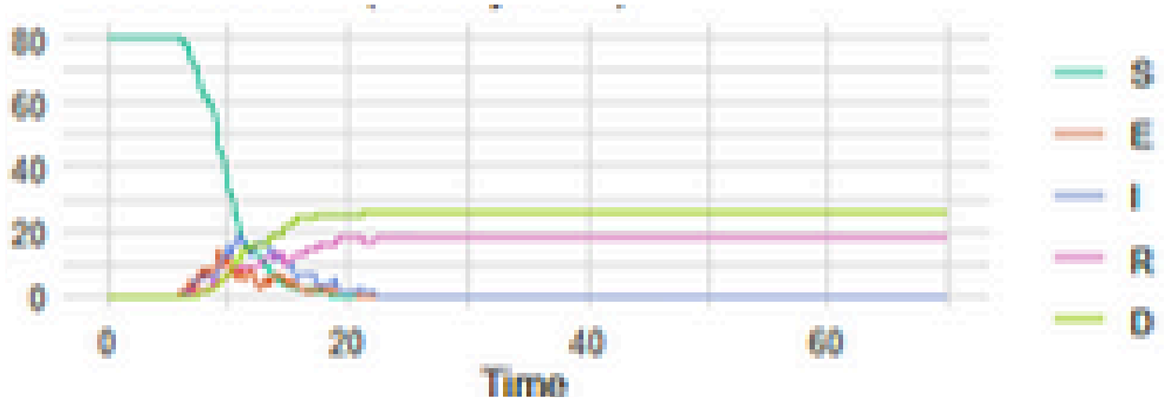
- For which species (demography, mobility) and in which disease context can this mitigation measure be beneficial at the metapopulation scale?
- To what extent does this measure increase the risk of contaminating other species?
- What would be the best way to proceed?

METHOD

- **Step 1 - Building a model:**
  - That captures epidemiological, demographical and movement processes in a metapopulation
  - Stochastic model
  - Compartment model
  - Continuous Time Markov Chain
  - Tau-Leap algorithm

  - Response variables:
    - Number of survived adults and nestling
    - Number of infected colonies
    - Number of infected individuals X times at sea





Modeling choices:

Model → Deterministic / Stochastic

Stochastic → Agent-based / Compartment-based

Compartment-based → Discrete Time / Continuous Time

Continuous Time → Gillespie algorithm / Tau-Leap algorithm

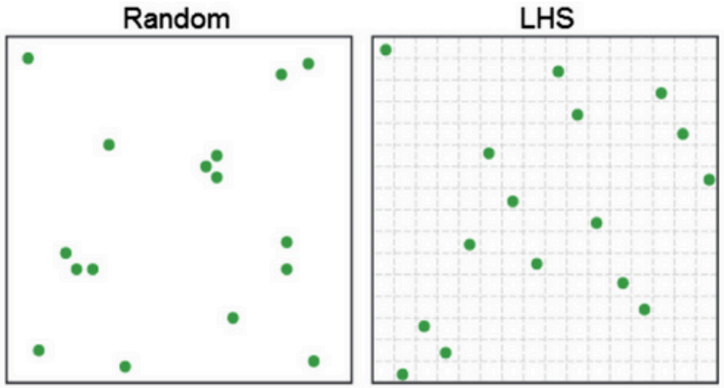
MODELING

- **Scenarios**:
  - HS: Baseline on a Healty Site
    - No initial infected breeder and no induced dispersal
  - BO: Baseline on an Outbreak site
    - **One initial infected breeder** and no induced dispersal
  - RS: Reactive Strategy
    - **One initial infected breeder** and **dispersal induced** after two days of the first death
  - PS: Proactive Strategy
    - No initial infected breeder and **induced dispersal**
    - Proactive measure e.g., outbreak detected in a neighboring species (not in the model)
  - P2: Proactive Strategy - Too late
    - **Initial infected breeder not detected** and **induced dispersal**
    - “Too-late” proactive measure

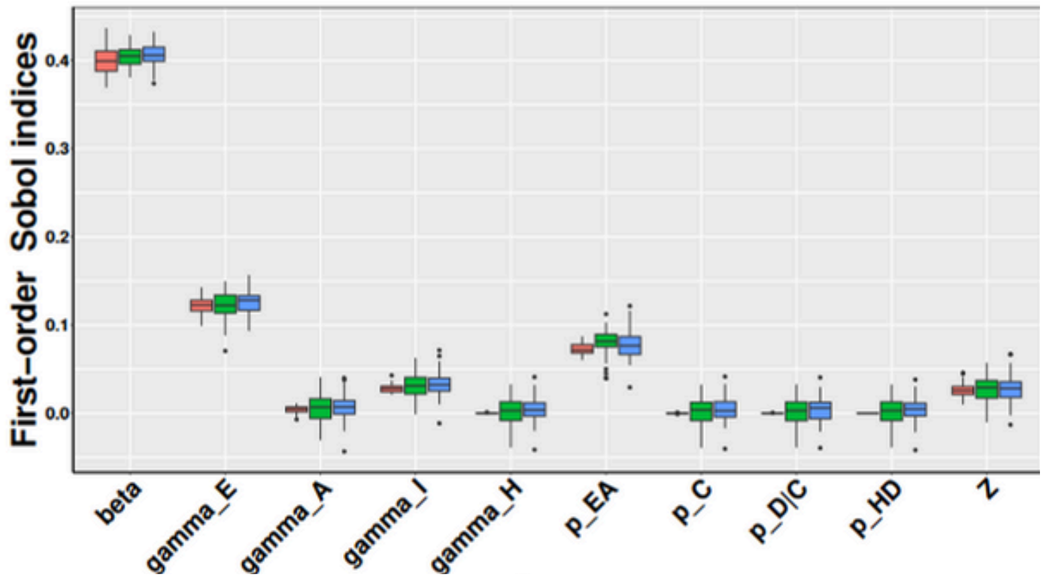
METHOD

- **Step 2 - Sensitivity analysis:**
  - Latin Hypercube sampling
  - Hierarchise parameters contribution and interactions
  - Identify threshold

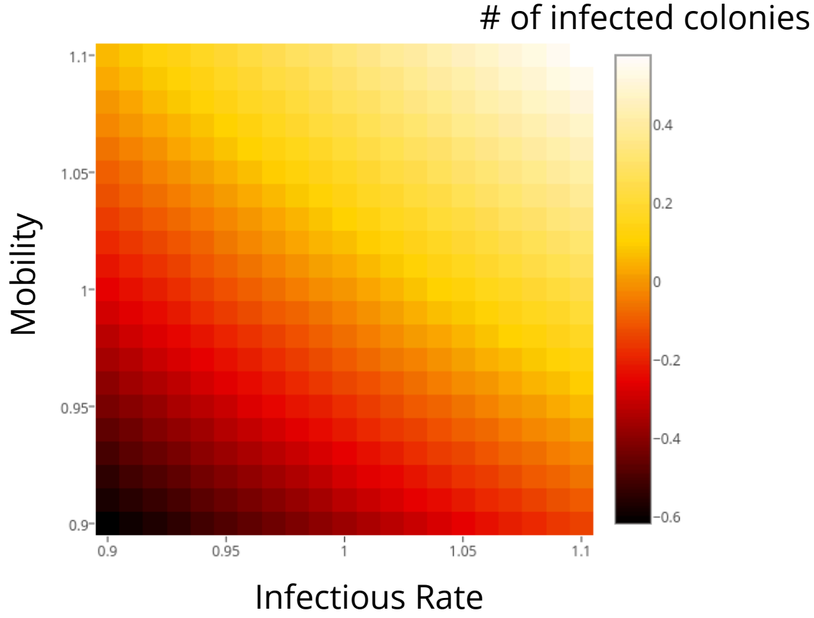
Latin Hypercube Sampling



Variance-based sensitivity analysis



Heatmaps



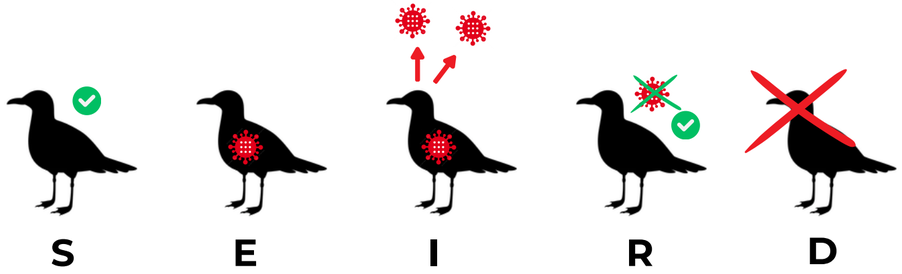
MODELING

- Epidemiological status:
  - Susceptible (S)
  - Exposed (E)
  - Infectious (I)
  - Recovered (R)
  - Dead (D)

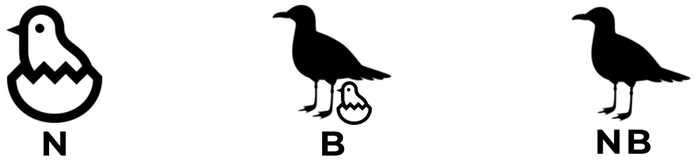
- Reproductive status:
  - Nestling (N) - immobile
  - Breeder (B) - attached to a colony
  - Non-Breeders (NB) - prospecter

- Localisation:
  - Colonies A, B, C
  - Breeder seas, associated to a colony
  - Non-Breeders sea, connected with all colonies

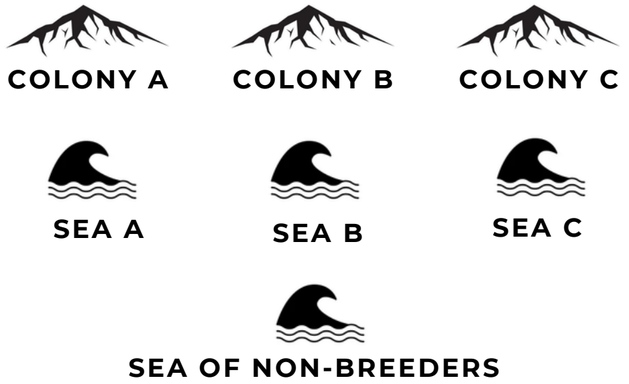
Epidemiological status



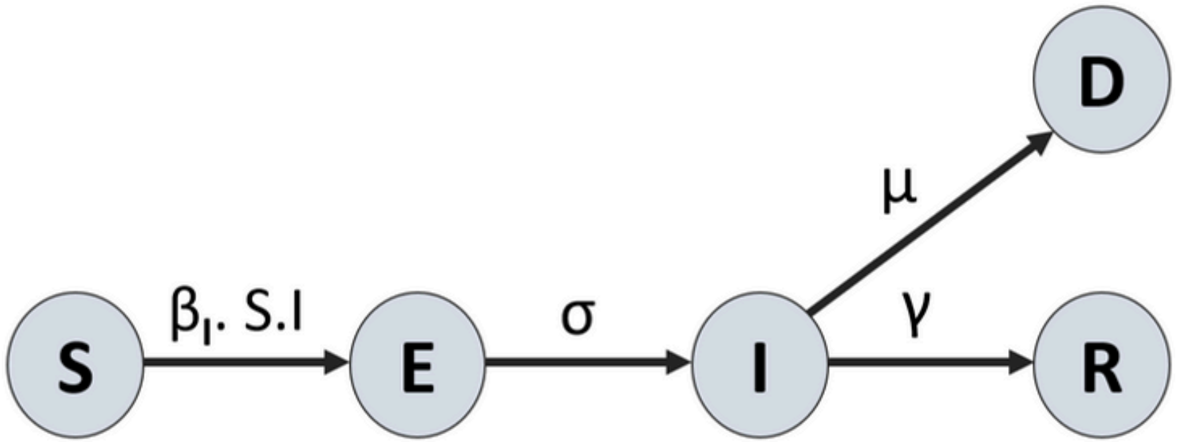
Reproductive status



Localisation



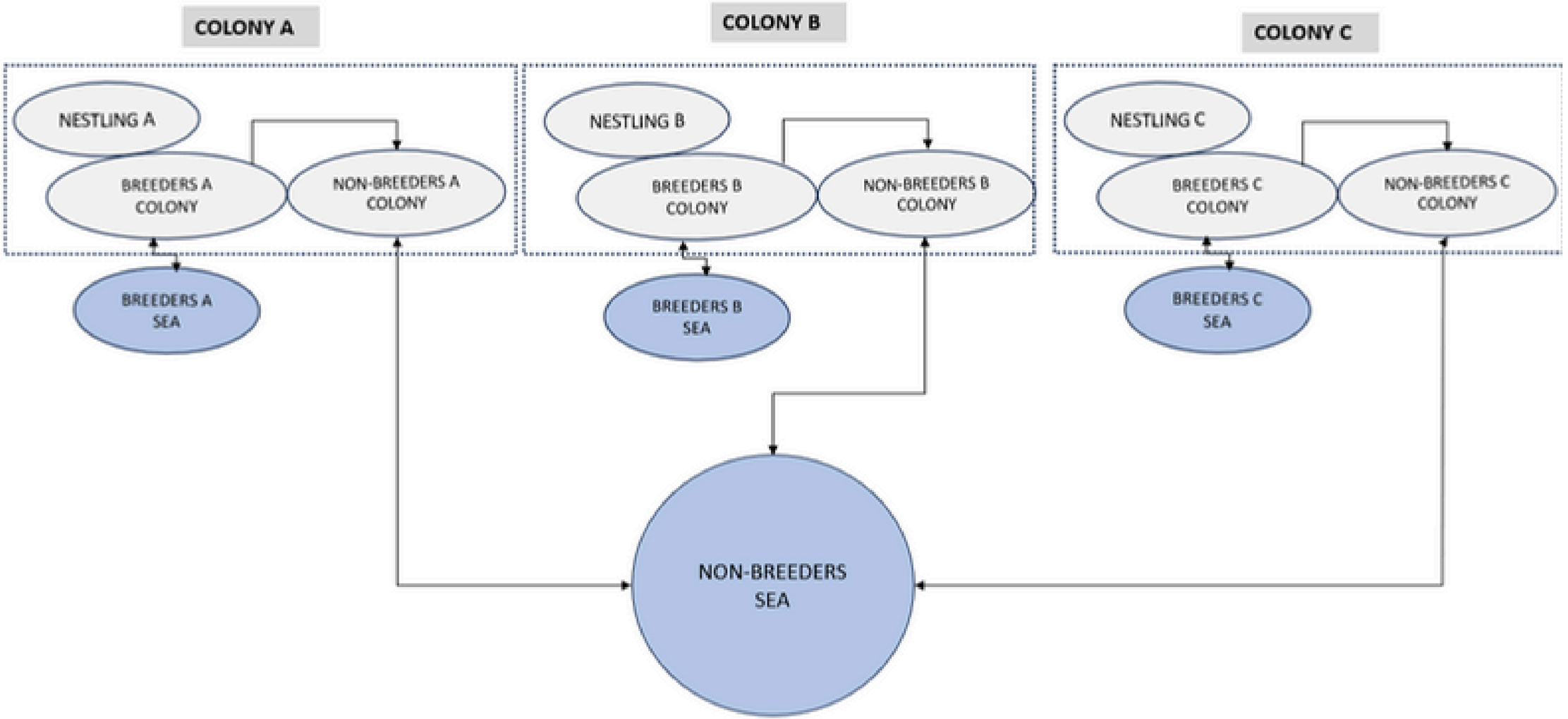
MODELING



Conceptual diagram of the epidemiological model

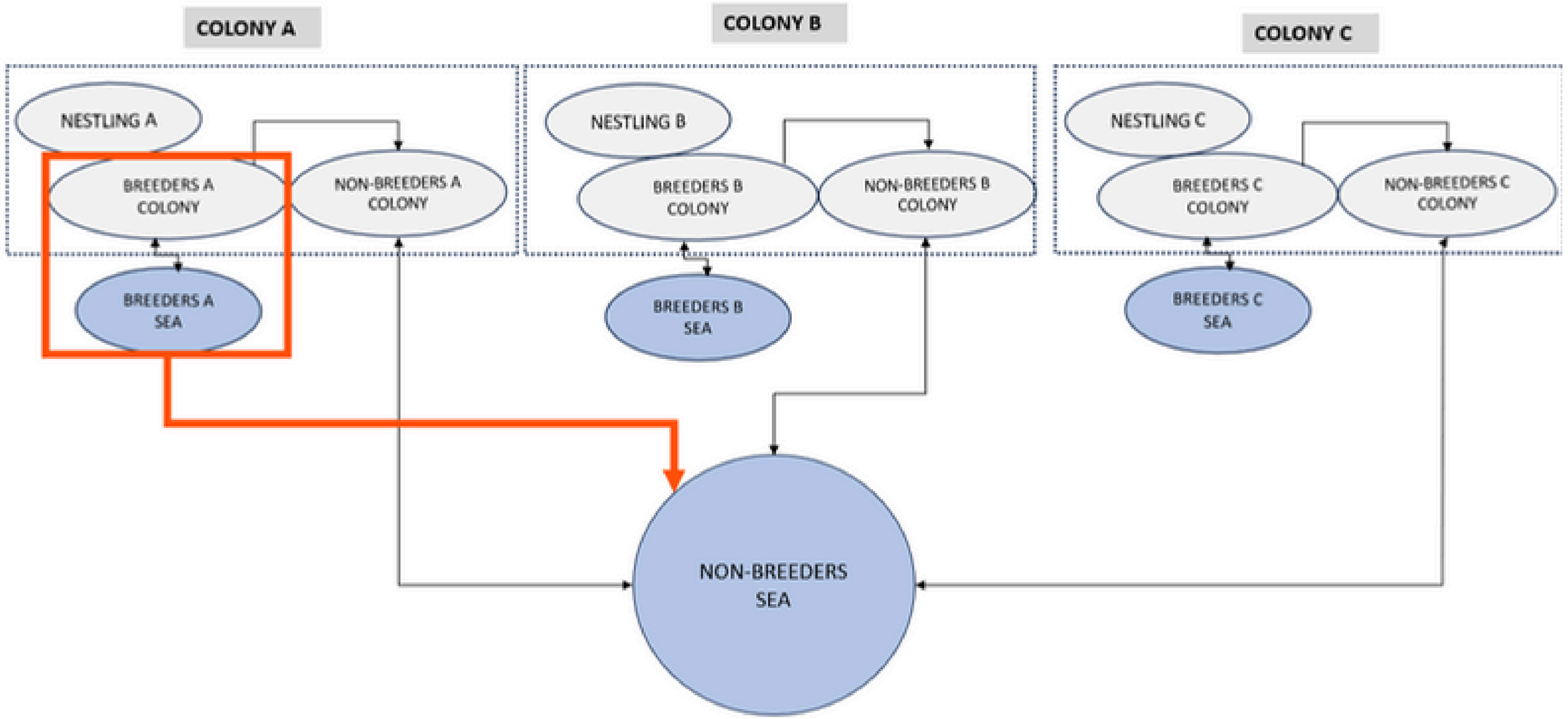
MODELING

Overview of the spatial transmission process



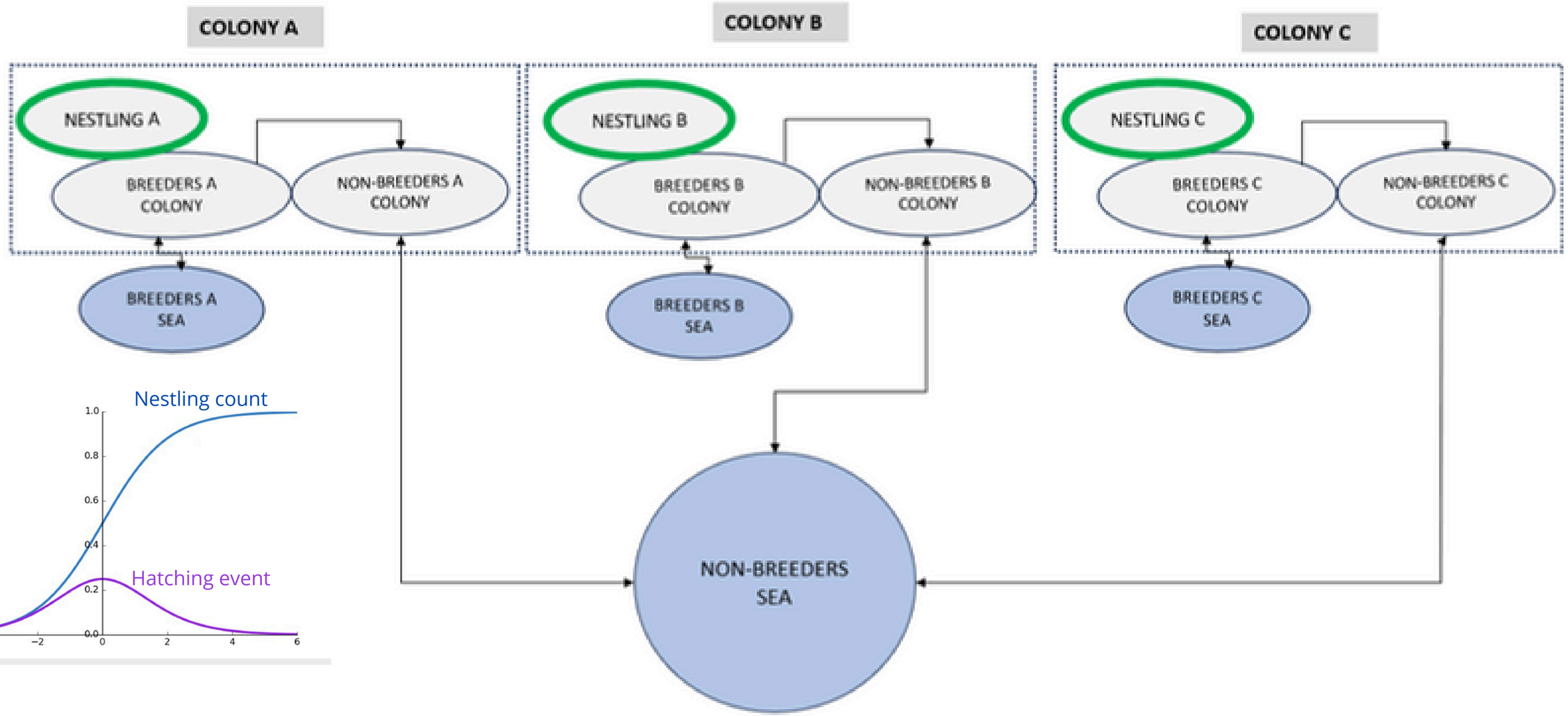
MODELING

Special events : **Induced dispersal**



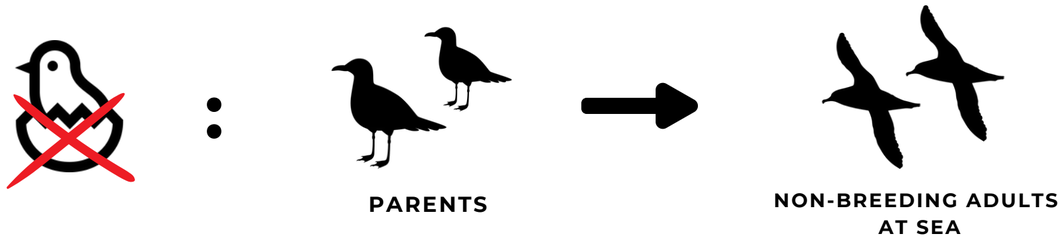
MODELING

Special events : **Nestlings hatching**

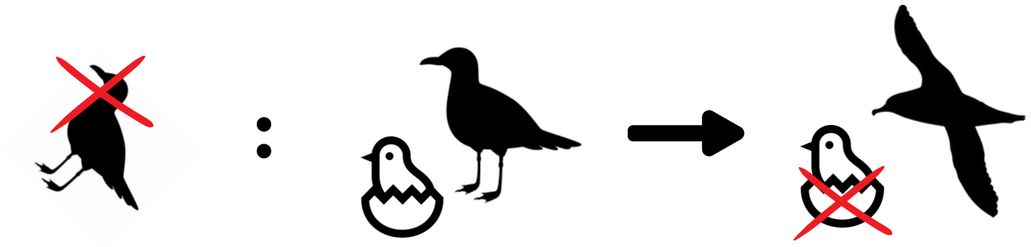


MODELING

- **Combined event:**
  - The death of a nestling leads to two breeders becoming non-breeders

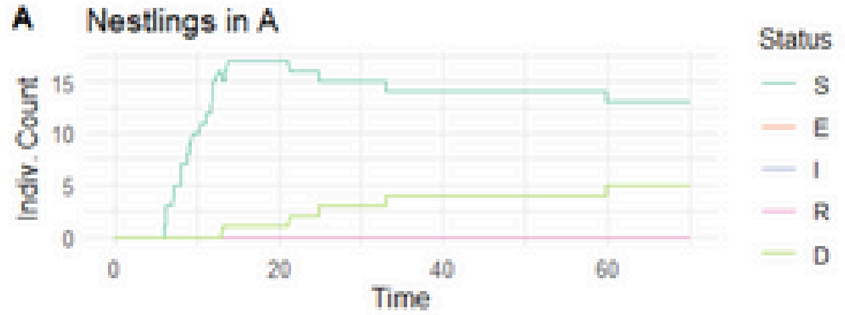


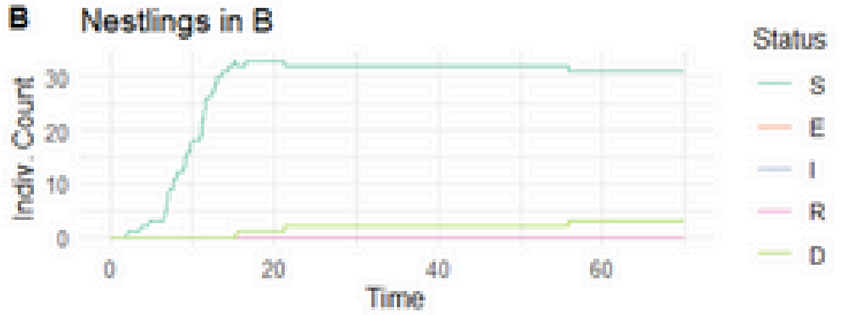
  - The death of an adult leads to one breeder becoming non-breeder and one chick dying

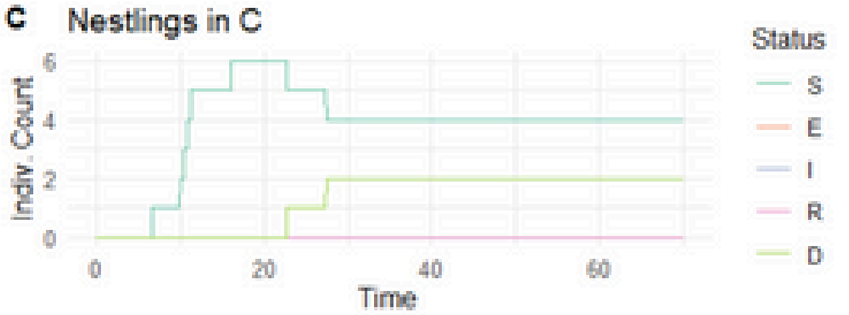


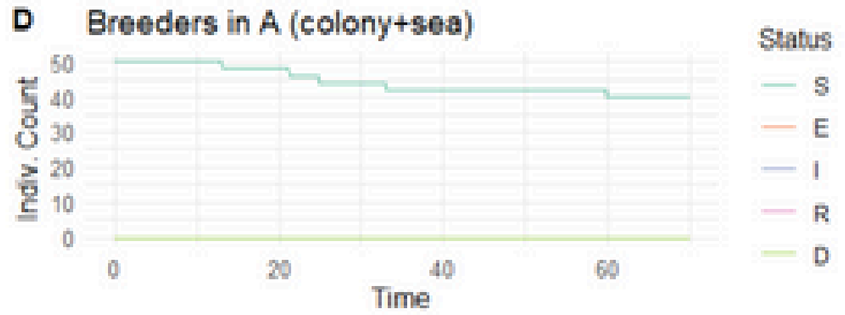
FOR NOW

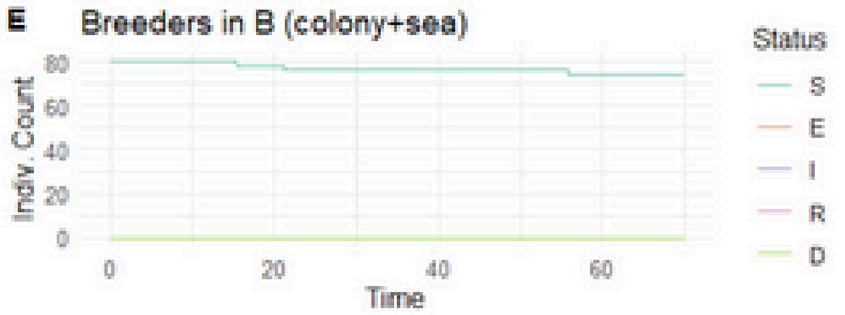
SCENARIO : HEALTY SITE

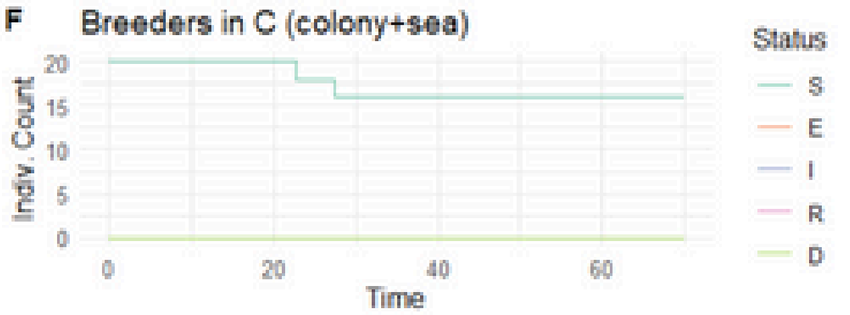


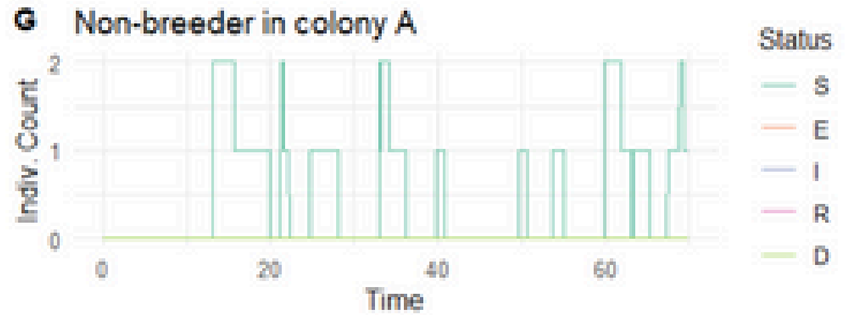


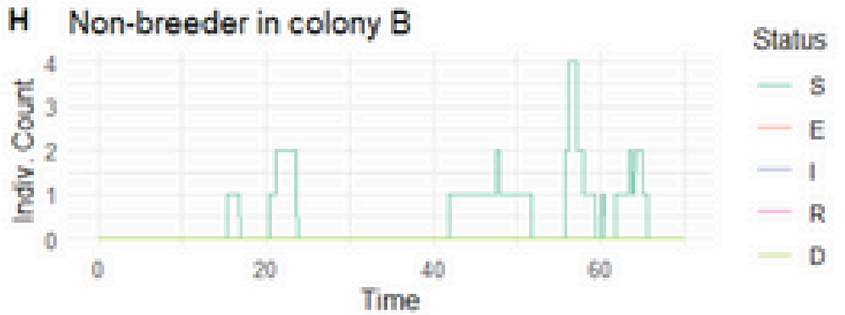


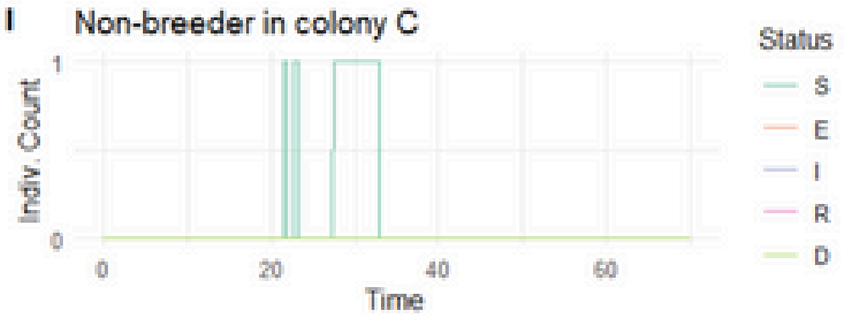


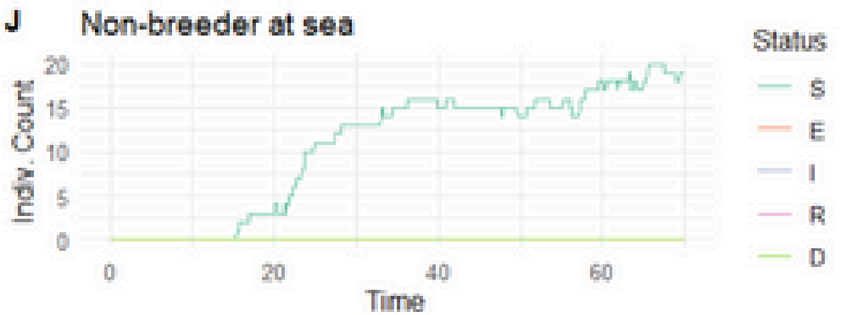






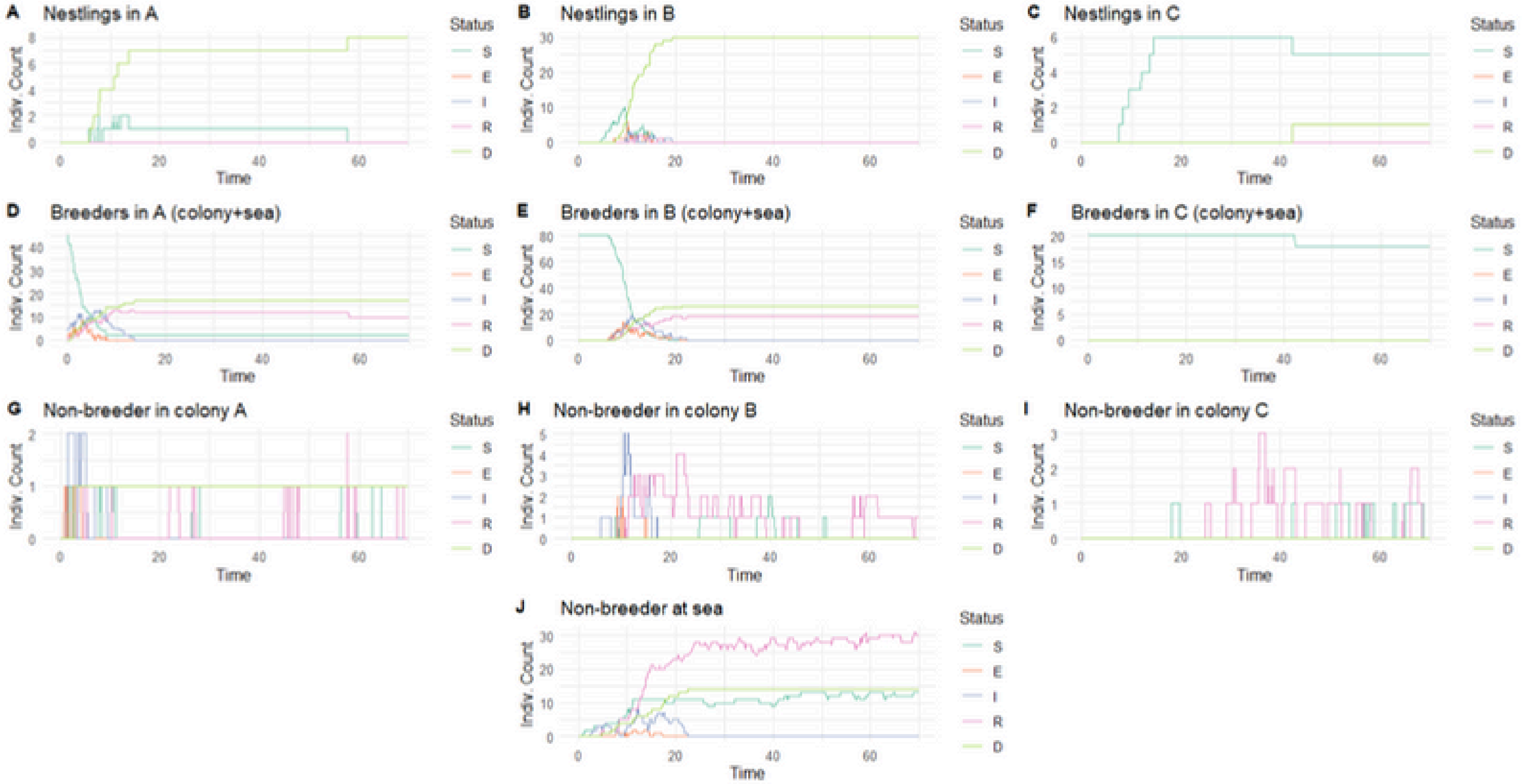






FOR NOW

SCENARIO : BASELINE OUTBREAK



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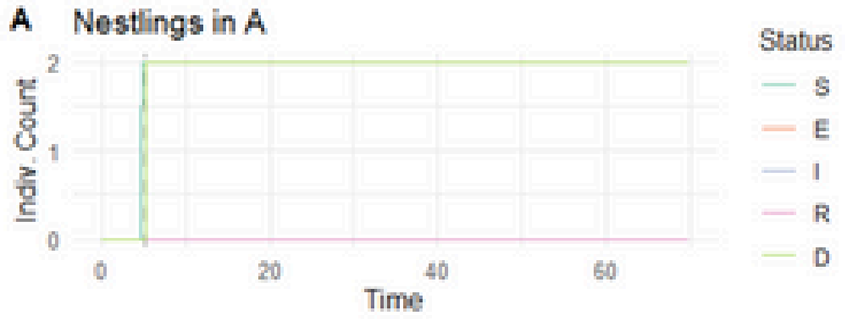
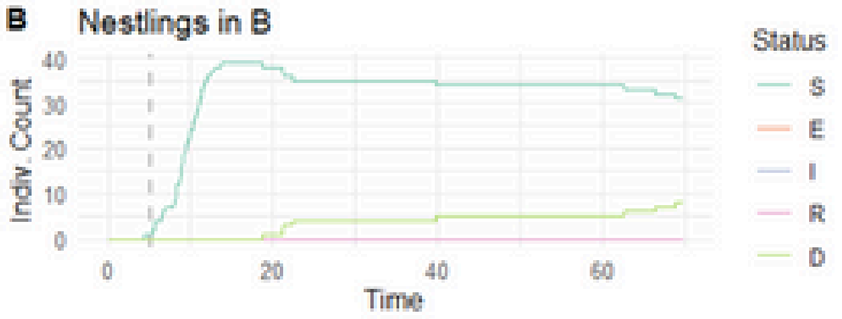
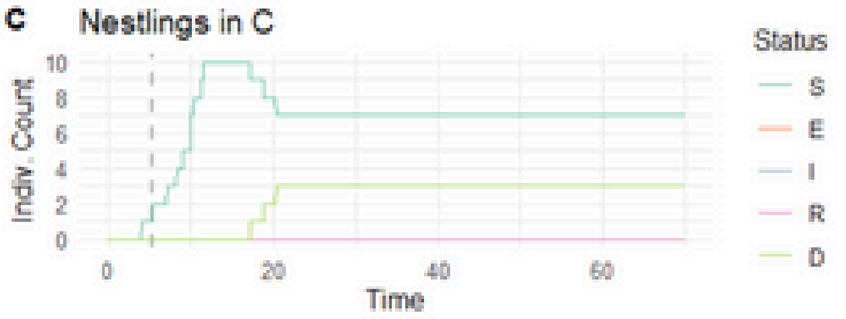
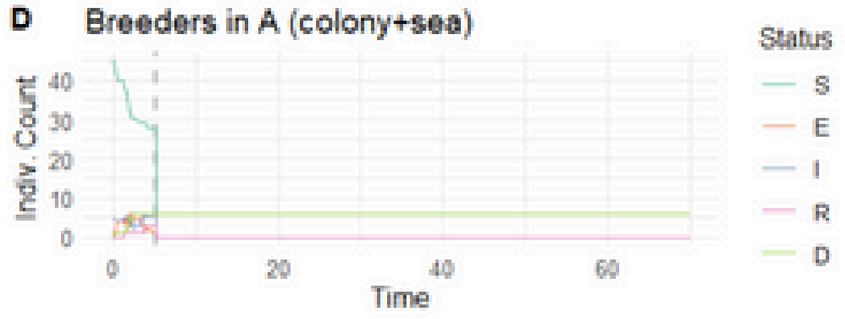
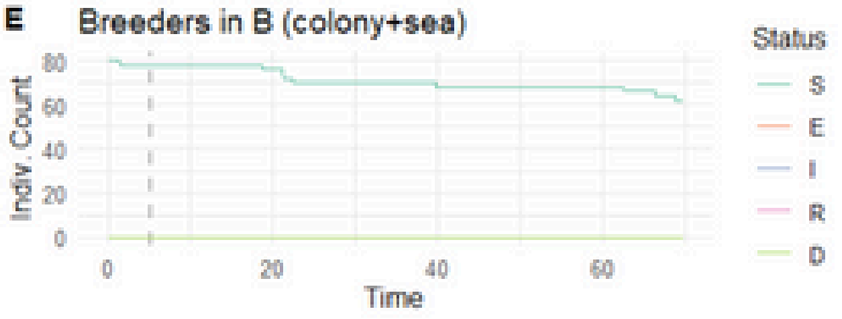
SCENARIO : REACTIVE STRATEGY

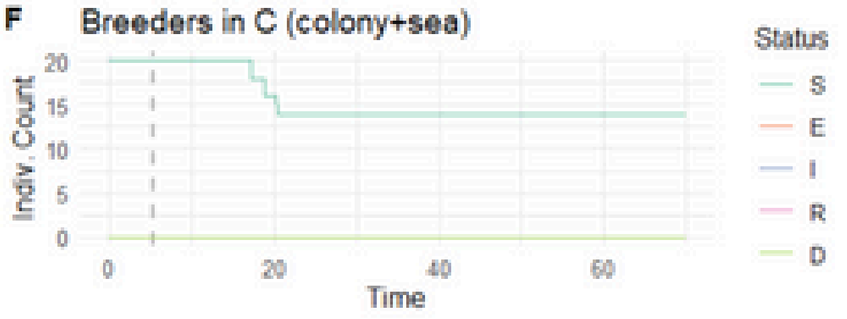


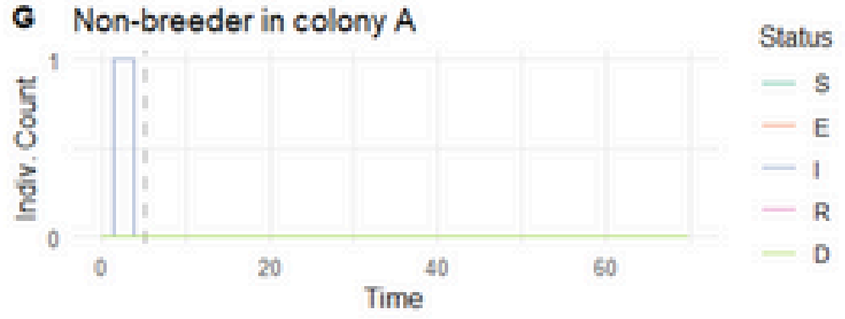


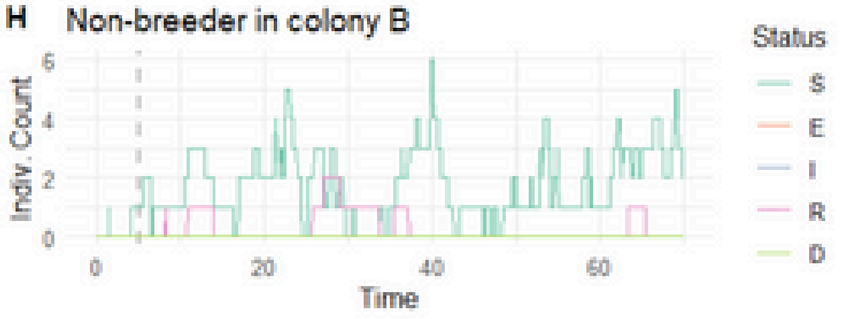


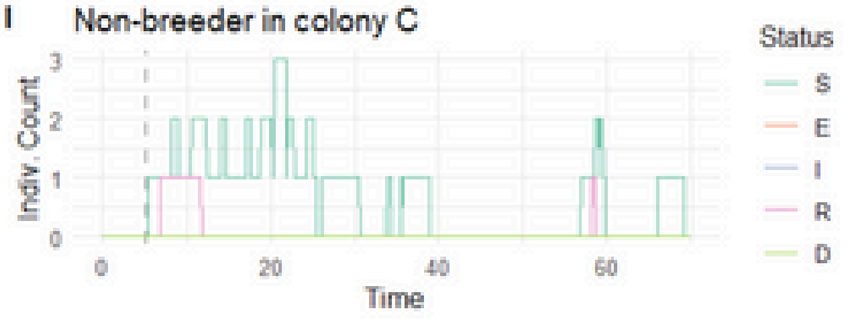


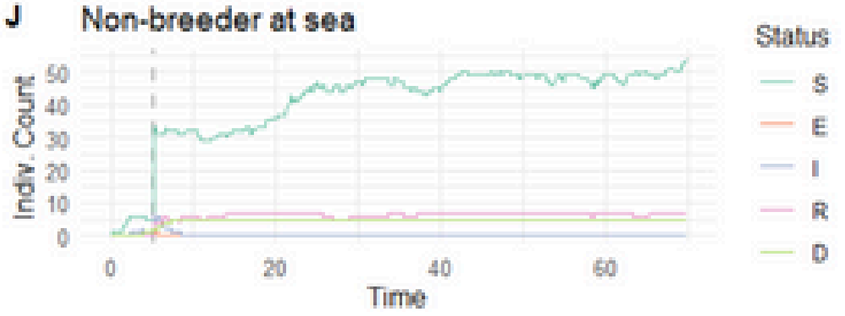






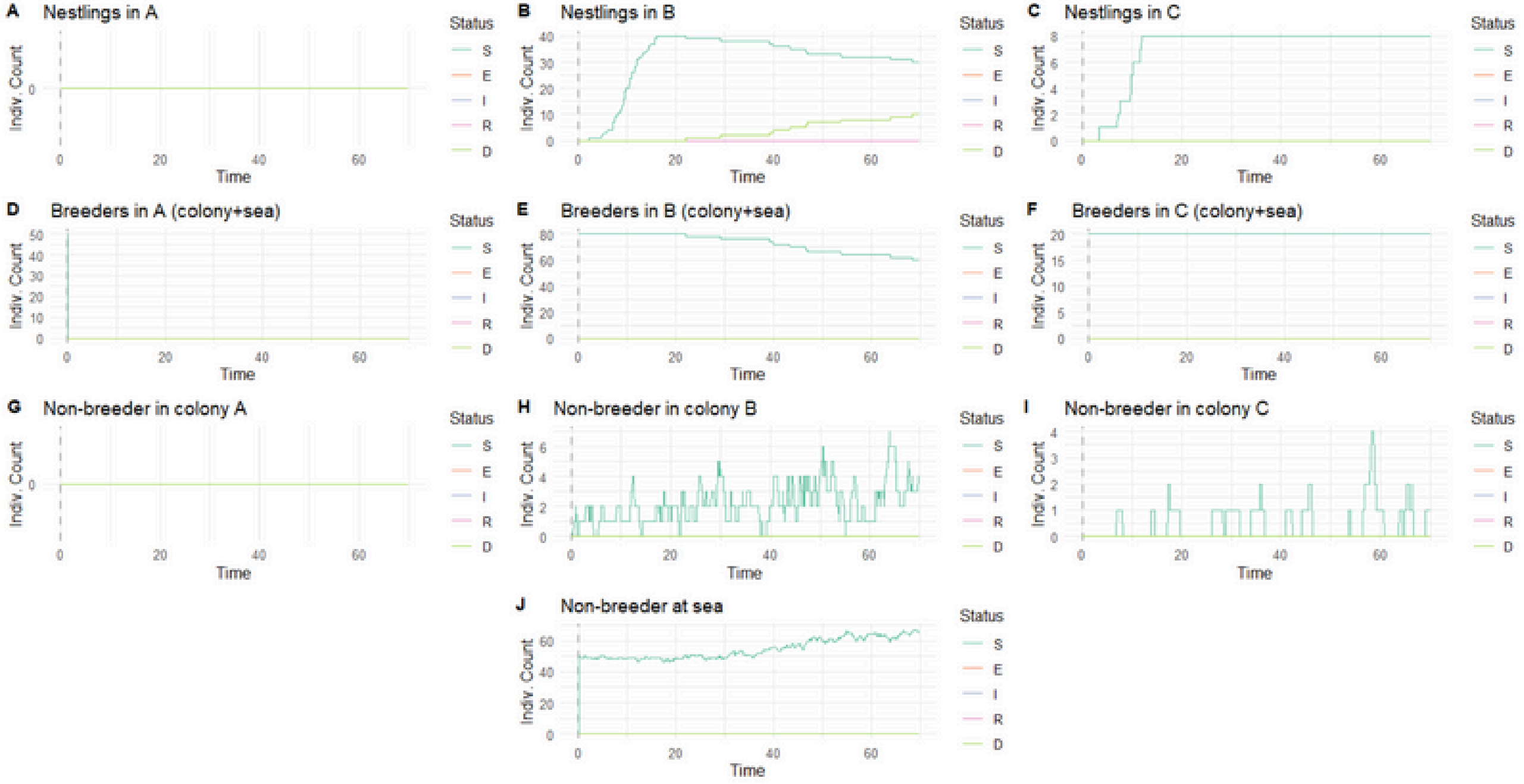






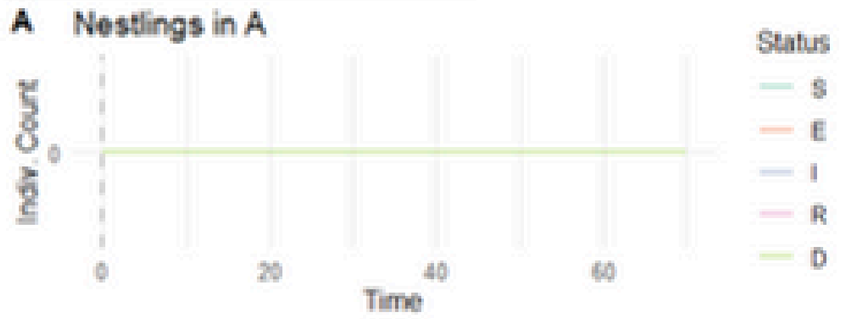
FOR NOW

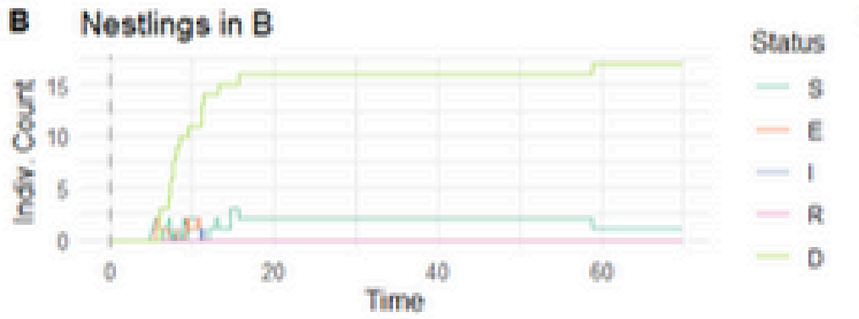
SCENARIO : PROACTIVE STRATEGY

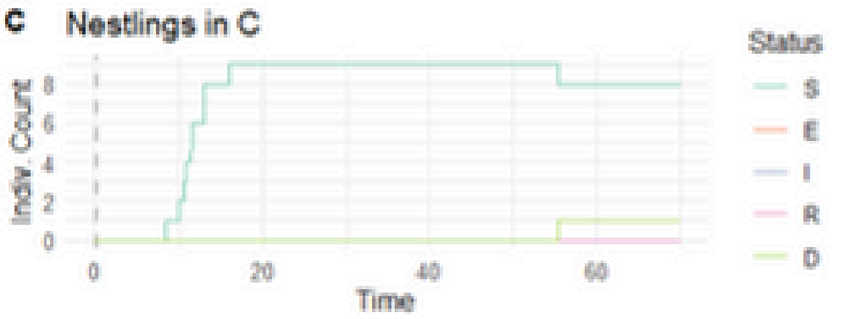


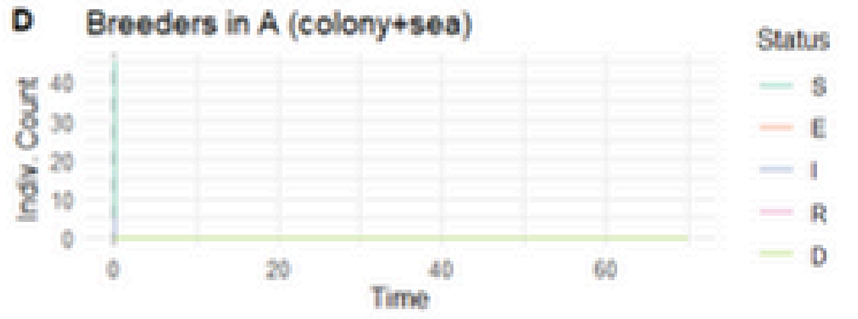
FOR NOW

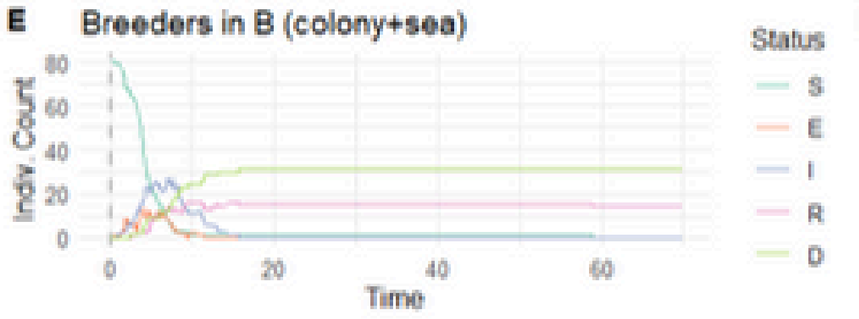
SCENARIO : PROACTIVE STRATEGY - TOO LATE

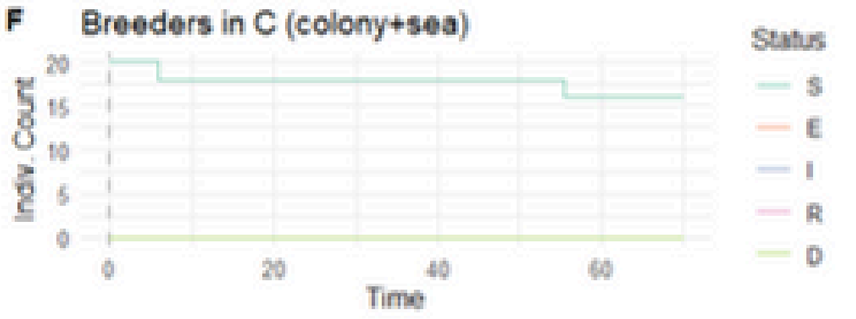


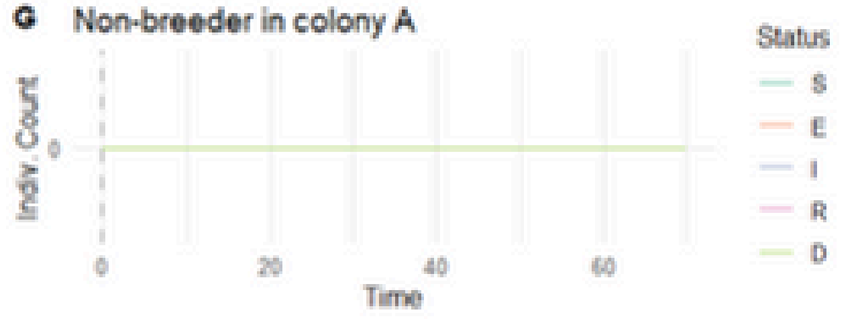


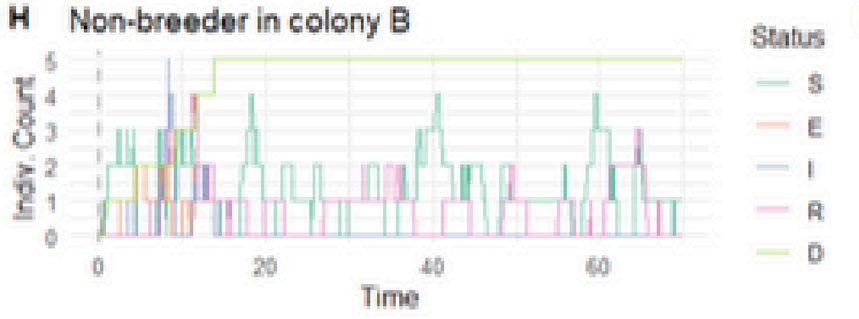


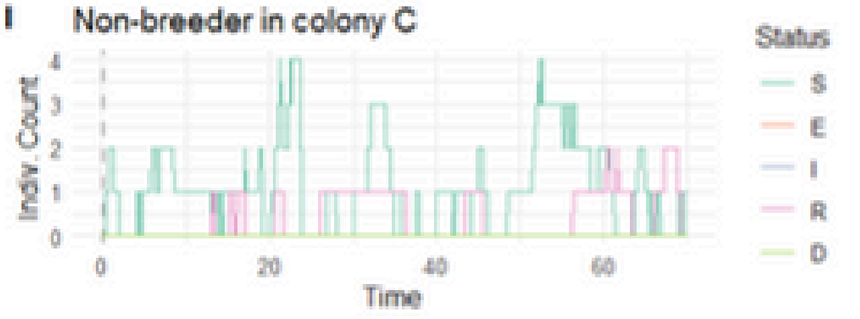


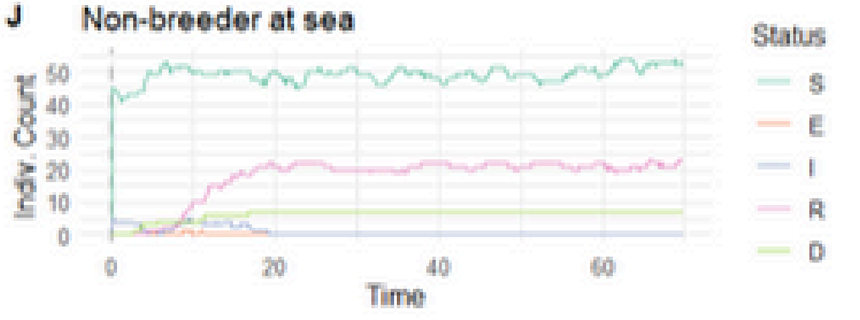












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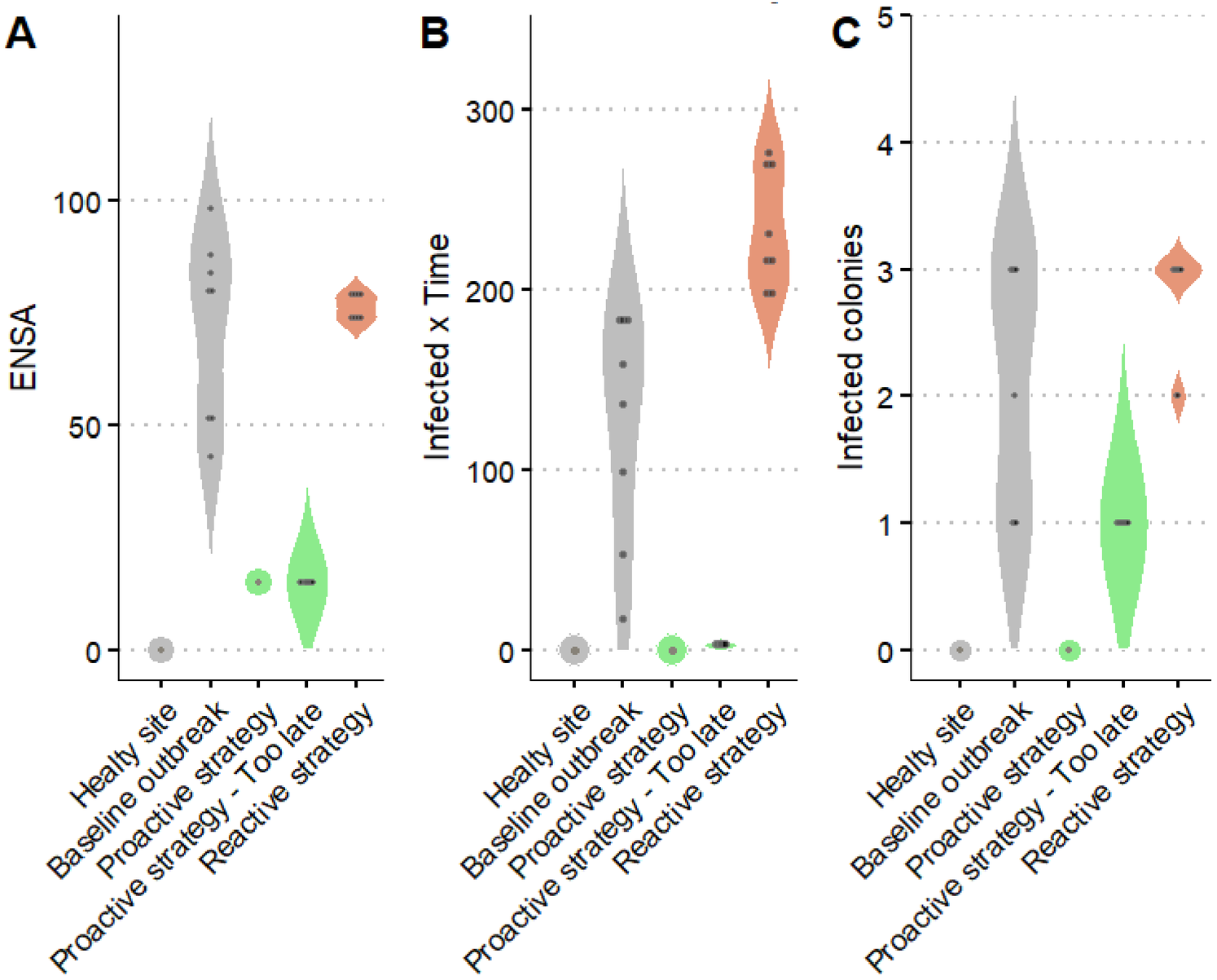
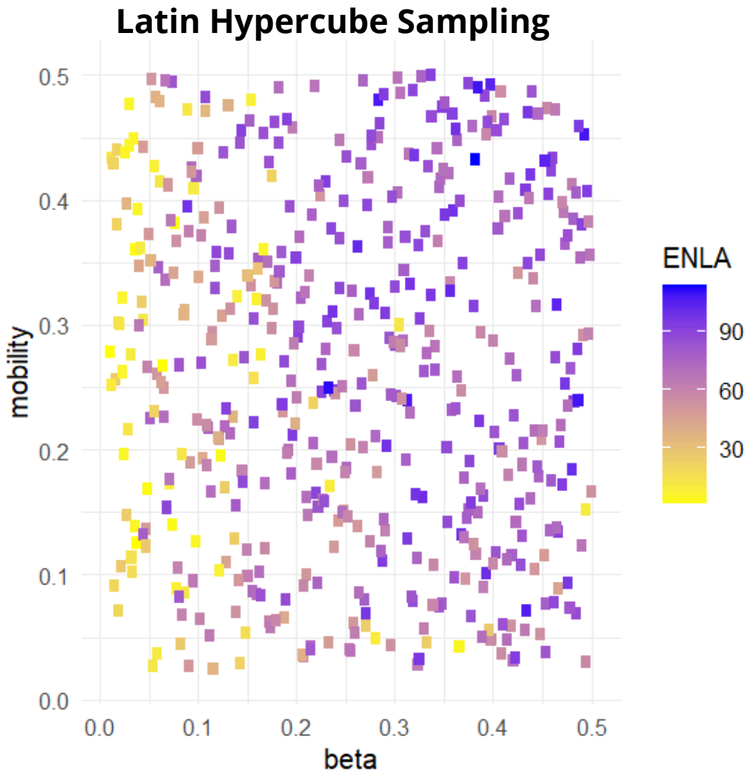


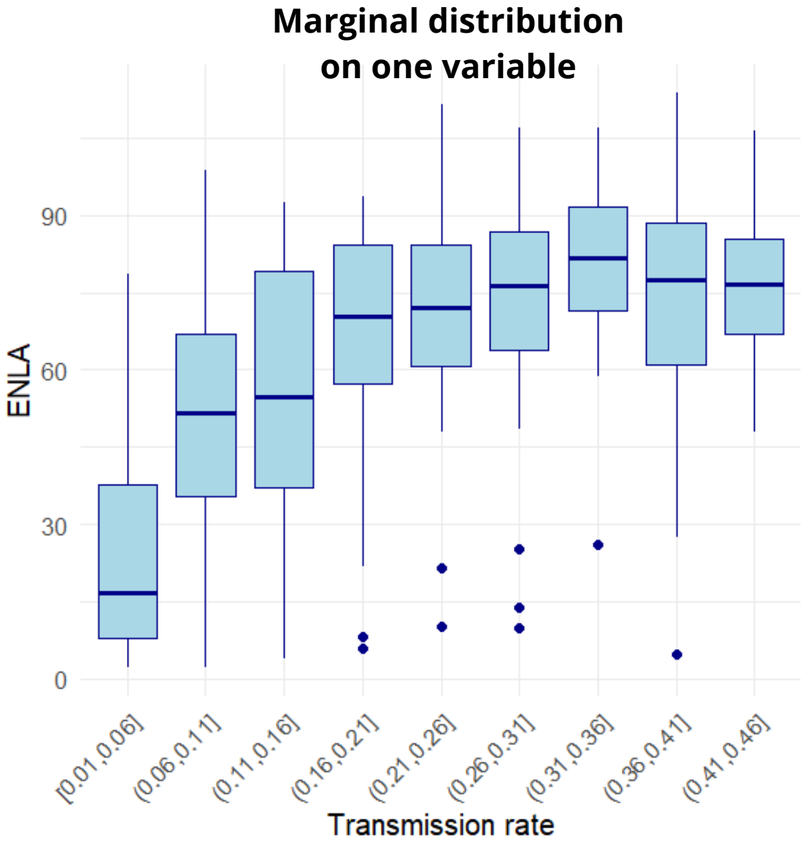
ENLA :
Equivalent Number of Lost Adults
= Adults +
P(access reproduction) x Nestling

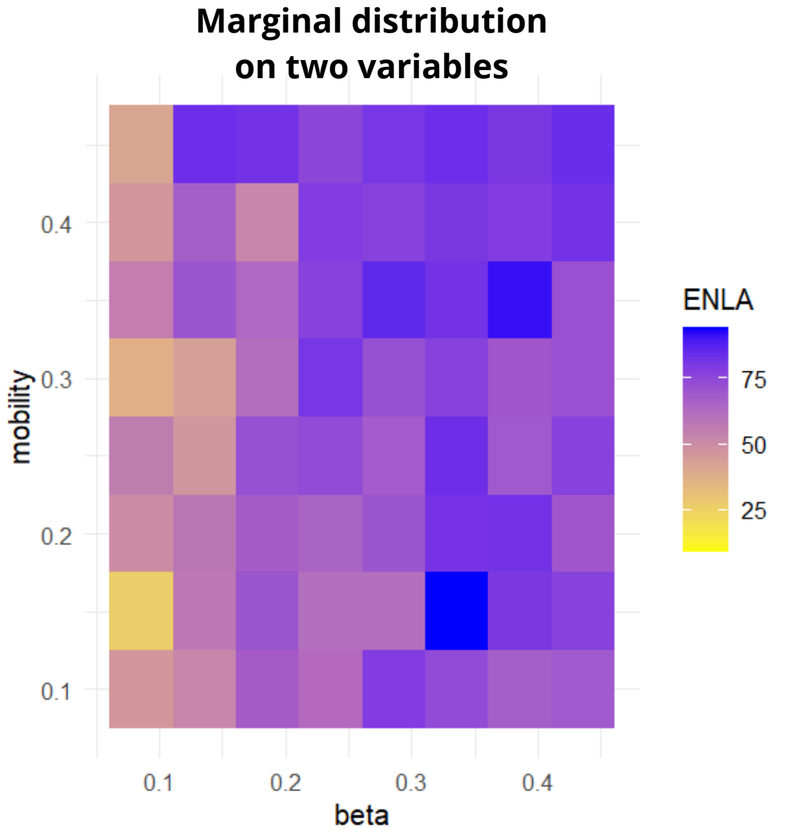
Infected x Time:
Infected by time integral in the compartment "Sea of Non-breeders"

Infected colonies :
Number of colonies with at least one infected individual over the monitoring period

FOR NOW


Latin Hypercube Sampling
mobility
beta
ENLA
90
60
30
0.0
0.1
0.2
0.3
0.4
0.5


Marginal distribution
on one variable
ENLA
Transmission rate
0
30
60
90
[0.01,0.06]
(0.06,0.11]
(0.11,0.16]
(0.16,0.21]
(0.21,0.26]
(0.26,0.31]
(0.31,0.36]
(0.36,0.41]
(0.41,0.46]


Marginal distribution
on two variables
mobility
beta
ENLA
0.1
0.2
0.3
0.4
25
50
75