Depuration Dynamics of Norovirus in Oysters

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Project Aims

• Construct a mathematical model of norovirus (NoV) dynamics in depuration (current stage)
• Case study of oyster farm location(s) (next stage)
• Recommend control strategies for NoV mitigation

Reduce NoV in Oysters: Reduce NoV Outbreaks
Oyster Depuration – What Is It?

- Oysters are flushed with clean, oxygenated water
- Reduces bacterial (E. coli) & particulate contaminants
- Limited impact on virus loads in oysters
- Costly to depurate
- Only method used in supply chain for NoV mitigation
Norovirus Testing in Oysters

- Current testing method – **RT-PCR**
- PCR testing is **expensive** – £10,585 for 50 sample data set
- **Modelling NoV** very important and inexpensive
- Oyster’s **Digestive Gland** – **IS tested** for NoV load
- **Rest of Digestive System** contains NoV – **NOT tested**
- **Whole oyster is eaten** – potential **NoV under-reporting**

Can we extrapolate NoV load in whole oyster from detectable NoV load?
Depuration Model Considerations

Consider 3 separate aspects of NoV and combine into one overall model:

- Single oyster’s internal NoV dynamics
- Population’s NoV distribution pre-depuration
- Depuration effect on population’s NoV distribution
Internal NoV Dynamics

Oyster \( (z_t) \)

Pre-gland system \( (y_t) \)

Digestive gland \( (x_t) \)

‘Risk’ Value

‘Observable’ Value

\[ k \]

\[ b \]
NoV Internal Dynamics Model (1)

A compartmental model:

\[ \frac{dy}{dt} = -ky \quad \text{(Pre-Gland System Model)} \]

\[ \frac{dx}{dt} = ky - bx \quad \text{(Gland System Model)} \]

\[ z_t = x_t + y_t \quad \text{(Whole Oyster Model)} \]

Where: 
- $k$ – rate of NoV flow into Gland from Pre-Gland system (metabolic rate)
- $b$ – rate of NoV flow out of Gland into external water (depuration rate)
Initial conditions at $t = 0$ where $x_0 = Az_0$ and $y_0 = (1 - A)z_0$:

Solution set of the model is:

\[
x_t = \Theta(t) \ x_0
\]

\[
y_t = y_0 \exp\{-kt\}
\]

\[
z_t = \Omega(t) \ z_0
\]

Where $0 < A \leq 1, b \neq k$ and

\[
\Theta(t) = \exp\{-bt\} + \frac{k(1 - A)}{(b - k)A} (\exp\{-kt\} - \exp\{-bt\})
\]

\[
\Omega(t) = (b - k)^{-1} [(b - Ab) \exp\{-kt\} + (Ab - k) \exp\{-bt\}]
\]
Regression Calculation & Analysis

- Depuration data sets* analysed using non-linear regression and plotted
- Returned realistic values for parameters $A$, $b$, $k$
- Variance between risk and observable NoV regression values is mainly dependent on the values of $A$ and $t$

*Data courtesy Anna Neish - Cefas
Lognormal distribution functions for observable and risk values at $t = 0$:

$$P(x_0) = \frac{1}{\sigma \sqrt{2\pi x_0}} \exp\left(\frac{(-\ln(x_0) - \mu)^2}{2\sigma^2}\right)$$

$$P(z_0) = \frac{1}{\sigma \sqrt{2\pi z_0}} \exp\left(\frac{(-\ln(Az_0) - \mu)^2}{2\sigma^2}\right)$$
Population’s NoV Distribution – During Depuration Model

- $x_0 \sim x_t$ and $z_0 \sim z_t$ by the continuous, differentiable functions $x_t = \Theta(t)x_0$ and $z_t = \Omega(t)z_0$
- Can transform $P(x_0), P(z_0)$ to derive $P(x_t), P(z_t)$:

\[
P(x_t) = \frac{1}{\sqrt{2\pi\sigma x_t}} \exp\left(-\frac{(\ln(x_t/\Theta(t)) - \mu)^2}{2\sigma^2}\right)
\]

\[
P(z_t) = \frac{1}{\sqrt{2\pi\sigma z_t}} \exp\left(-\frac{(\ln(Az_t/\Omega(t)) - \mu)^2}{2\sigma^2}\right)
\]
Model v Regression Results

• Model results show close correlation to previous regression plots

• When $0 \leq t \leq \sim 60$:
  
  Risk > Observable

• Model infers that NoV testing should take place after 60 hours of depuration to reflect accurate NoV test results

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Summary of Results

• Can extrapolate Risk values from Observable values

• Closely replicates experimental data behaviour

• Demonstrates that NoV testing currently underreports NoV loads if carried out too soon after harvesting

• Can be used to plan effective NoV testing strategies in oysters
Further Model Work

• Sensitivity analysis of model, any aberrant behaviour when varying values of $A, k, b$?

• Analysis of ‘tail population’ – probability density of distribution which is greater than some threshold value

• Verify model results against (any) further experimental data

• Recommend NoV prevention/detection strategies based on findings
Thank you for listening...

Impact Collaborative Studentship funded by:

The University of Stirling
and

Centre for Environment, Fisheries & Aquaculture Science

Computing Scientist – Brian Lee (UoS)