Estimating Salmon Price Rise Due to the Increased Presence of Lice Caused by Global Warming: A Petri Net Based Approach

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***Abstract* - This paper describes a conceptual model to estimate how global warming will lead to increased salmon aquaculture costs due to the increased presence of salmon lice (which are known to favour warmer climates). Usually, analytical models are used for this kind of simulation. However, this paper presents a Petri Net model for this purpose, with the expectation that the Petri net modules can clearly identify the different stages of the salmon aquaculture. The Petri net model also incorporates a neural network to learn from the data fed into the model. Hence, the authors present the model as a conceptual model of assistance to those who want to build advanced models. However, the simulations run with this model took an unexpectedly long time; the long simulation time makes Petri Net's application for modelling this type of problems questionable.**

Keywords* - *Salmon aquaculture costs, Petri Nets, GPenSIM.

I. INTRODUCTION

Aquaculture is an important industry in Norway, accounting for some NOK 68 000 million annually [1]. For several years the industry has been troubled by salmon lice, not just in Norway but also internationally [2]. The prevalence of salmon lice has led to significantly increased costs, both due to the salmon lice injuring the fish directly and the cost of treatment [3], [4].

It is known that salmon lice favour warmer temperatures [5]. Global warming is a well-documented phenomenon [6], [7]. And will affect Norwegian coastal temperatures [8], [9]. Hence, it is important to conduct simulations to quantify the effect of global warming on salmon lice.

Background and Literature Study:

The master's thesis written by the first author of this paper (titled "Economic Effects of Global Warming: The Impact on the Life Cycle of Salmon Lice, With Knock-on Effects on Aquaculture and Angling Tourism") presents some details on the impact of Global Warming on Salmon lice. [10]. Several models also explain how salmon lice infection pressure is affected by temperature (e.g., [11]). Some models describe how salmon lice maturation rates are affected by temperature [12]. Further, some scientists have discussed the overall impact of global warming on aquaculture [13], [14].

Salmon lice (Lepeophtheirus Salmonis Krøyer, 1838) is a copepod species that infects both wild and farmed salmonids [15]. It passes through several stages including a larval stage during which it drifts freely waiting until it comes near enough to a salmon to latch onto it [16]. Infection Pressure estimates the amount of free-floating larvae in an area, taking into account salmonid population density, temperature, and infection rate [11].

Infection Rate is the ratio Salmonlice-Salmonids found in an area [17]. A high infection rate is considered highly undesirable, and if a specific limit is exceeded (depending on the time of year), medical intervention is required [18].

Petri Nets:

Due to spatial restrictions, this paper does not present the basics of Petri Nets. The interested reader is referred to [19] for basic definitions.

A tool that is known as General-purpose Petri Net Simulator (GPenSIM) [20] is used for the implementation of Petri Nets. GPenSIM supports distributing the model logic between the Petri Net ("hard wiring") and processor files ("soft coding") [21]. Hence, all the behaviors that cannot be (or difficult to) put on the Petri Net model are coded in the processor files.

GPenSIM has been successfully used for modeling Salmon farming to measure timing and throughput issues (E.g., [22], [23]). However, in this paper, the focus is on the estimation of the economic impact of salmon lice on aquaculture; GPenSIM is an ideal modeling tool for this purpose as it supports cost calculations too [24].

II. METHOD AND DESIGN

Fig.1 shows what we are trying to simulate using a Petri net model.

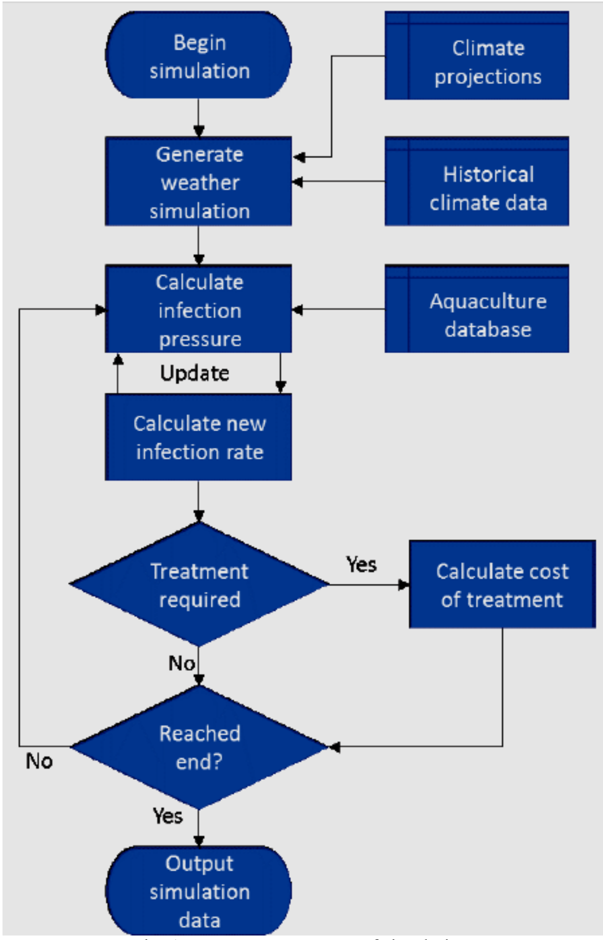

Fig. 1. Important segments of simulation.

The first active part of the simulation is to perform weather simulation. This part depends on climate projections (presumably with ROMS data [8], [9]) and historical climate data on the relevant regions of Norway, to generate a semi-random simulation of what the week by week temperature might be like in some future year.

The next part of the simulation is the infection pressure calculation. It receives information about infection rates and data on nearby aquaculture facilities. The method it uses for calculating infection pressure is described by [11] and also used by [10].

In the next part of calculating the new infection rate, a neural network is to be used that is trained on historical data, a priori. This part is to calculate the infection rate on a weekly basis.

In the part on "Treatment required", a choice is made whether to invoke treatment of salmon or not. If treatment is chosen, the simulation will proceed to "Calculate the cost of treatment" part.

"Reached the end" is the part where the time is checked against the time the weather simulator is supposed to cover. If yes, the simulation stops. Otherwise, the simulation jumps to the "calculate infection pressure" part.

The major task that is left is to develop a Petri net model that can support the simulation of all the parts described in Fig.1. The Petri Net is developed in section- III.

A. Extensions to the Petri Net

The P/T Petri Net lacks the modeling power to model real world problems [19]. Hence, some extension to P/T Petri net is unavoidable. Given below are some of the extension used in the modeling process presented in section-III.

Colored Petri Net: In P/T Petri net, tokens are homogeneous, and they carry no extra payloads (data). However, in the model that we are going to use, the tokens must carry data such as temperature, infection pressures, and infection rates. Hence, the color extension becomes necessary.

OR Gate: The use of an OR gate is not strictly required, but using it makes the whole model becomes easy to follow. Since OR gates are not a part of the standard GPenSim tool, an OR gate module was built and used in the model.

Inhibitor Arcs: Again, the use of inhibitor arcs is not strictly required, but they are used to make sure that there is only a single token at a time in certain key places. GPenSIM in-built function "tokenArrivedEarly" could also be instead of inhibiting arcs; however, inhibitor arcs seemed a more elegant and visible solution.

Semaphores: Because specific transitions need to fire in a particular order, we either have to use semaphores (a place with a token to exercise mutual-exclusion zone) or GPenSIM's in-built resources. Though both options are suitable, it was decided to use semaphores as these are visible in the Petri Net model itself (whereas GPenSIM's resources run in the background).

III. THE PETRI NET MODEL

Fig.2 shows the overall Petri Net model. It is clear from the model that the simulation starts by tokens being consumed from the place pWdata and then proceeds through various places and transitions until they pass into pResult. The following subsections present the details.

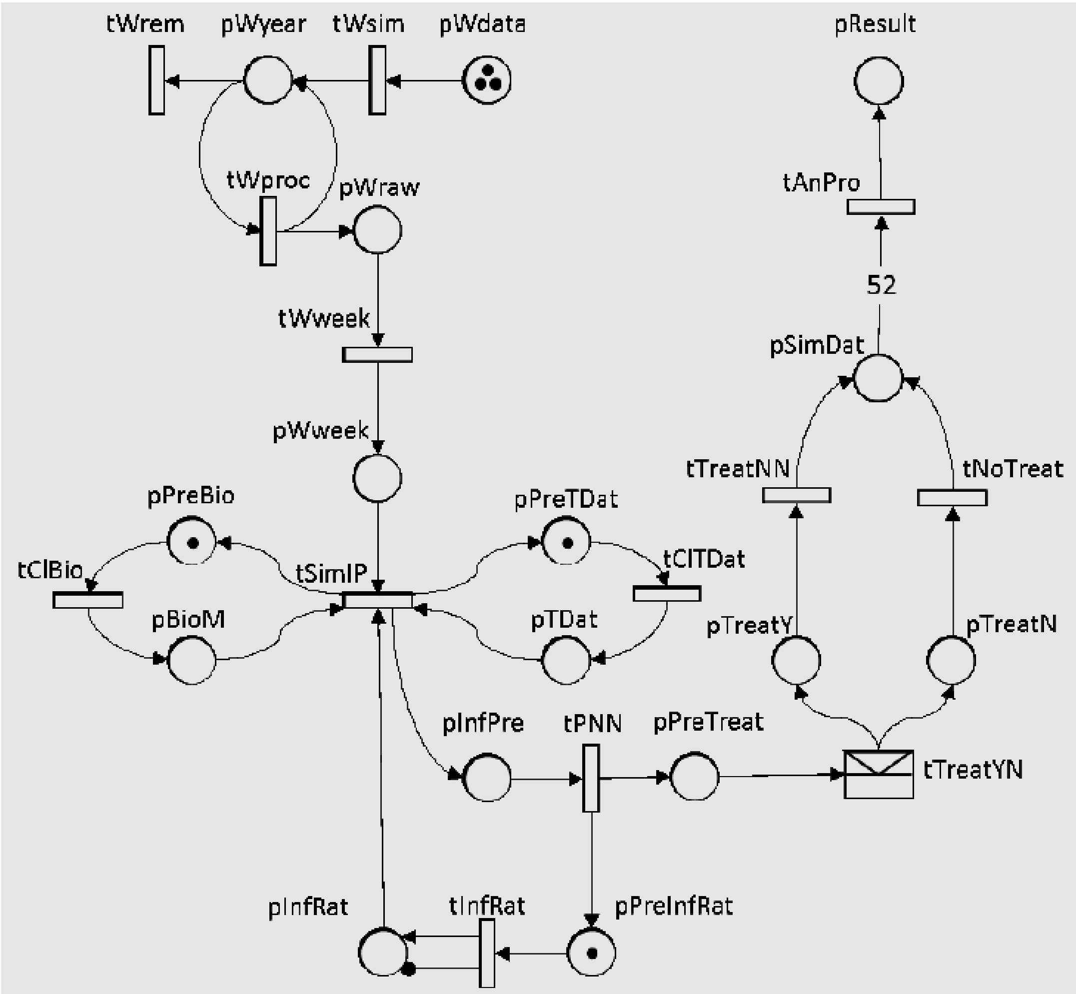

Fig. 2. The Petri Net Model

A. The Weather Simulation Module

This module represents the initial weather simulation (as shown in Fig.1 "Initial model flowchart"). This module is acivated by a token that is taken in from pWdata (Wdata for Weather Data) and receives a colour from tWsim (Wsim for Weather Simulator). tWsim functions as the input port of the module. Functions of the module:

- tWsim: This transition is where the actual weather simulation for the whole year would be generated.
- tWproc:Weather Processing. This transition processes the weather data week by week.
- tWrem: Weather Removal. Removal of weather data accumulation, after use.
- tWweek: Weather Weekly: The weekly weather being passed along to this transition, and this one picks the correct weekly data.

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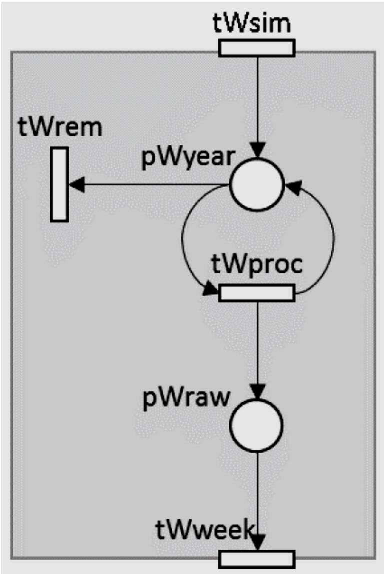

Fig. 3. The Weather Simulation

B. The Infection Pressure Module

The Infection Pressure Module handles the changes in the biomass over a period of time. [10] assumes constant biomass; however, the Infection Pressure Module is for increasing biomass.

As shown in Fig.4, the module has two cycles.

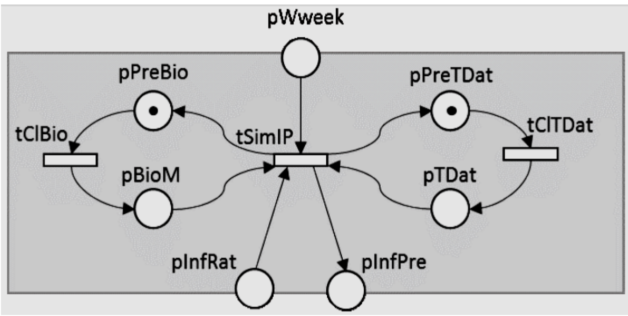

Fig. 4. The Infection Pressure Module

These carry information (colours) which are finally passed on to the place pInfPre. The functions of the transitions in this module:

- tSimIP: "SimIP" stands for Simulation of Infection Pressure. Given the data from the tokens in pBioM (population information) and pTDat (temperature data from all the past 20 weeks), tSimIP will calculate the infection pressure according to the algorithm developed by [11].
- tClBio: "ClBio" stands for Clear Biomass. tClBio strips away extraneous colours.

C. The Infection Rate Module

This module's purpose would be for a Neural Network (PNN) trained on historical data to estimate next week's Infection Rate. The estimated next week's infection rate will be used to update the data for the Infection Pressure.

The functions of the transitions in this module:

- tPNN: "PNN" stands for Pressure Neural Network. tPNN absorbs the data from the Infection Pressure algorithm and decides what next weeks infection pressure would be. tPNN also decides whether this level is such that treatment is required (in this version this is decided by random chance if we are in the right week section).

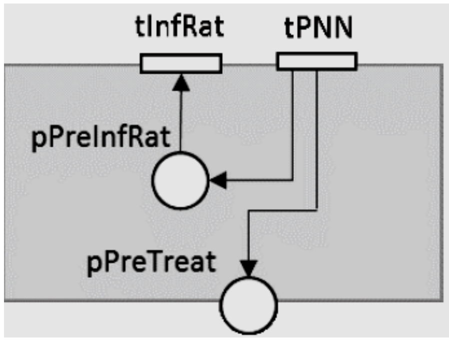

Fig. 5. The Infection Rate Module

- tInfRat: "InfRat" stands for Infection Rate. tInfRat purges unnecessary colours and sends the infection rate information on to pInfRat.

D. The Cost Module

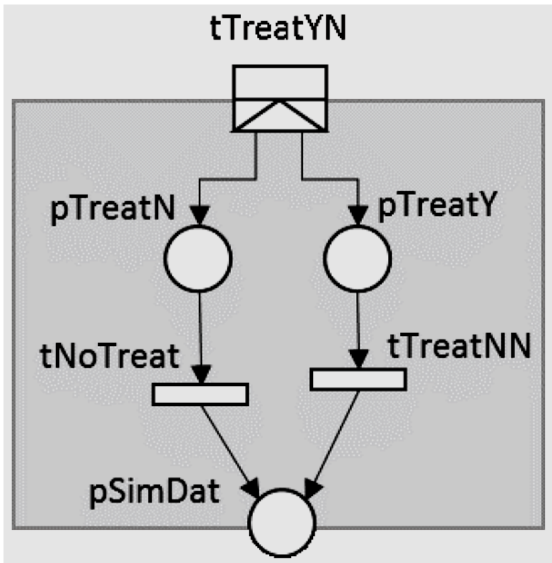

Fig. 6. The module for cost estimation

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The module for cost estimation (simply, the Cost Module) receives a token at the OR gate labelled tTreatYN at which point it is passed either to pTreatN or pTreatY. That is, conceptually treatment is either required for any given week, or it is not. If yes, we add the cost, if not we note there was no cost. The transitions of this module:

- tNoTreat: "NoTreat" stands for No Treatment.
- tTreatNN: "TreatNN" stands for Treatment Neural Network. tTreatNN gets all the past data, and it feeds the data into a (previously trained) neural network, and a cost of treatment is then calculated.

E. The Interaction between the Modules

Fig.7 shows the elements that connect the different modules together. Among the elements in the connector, the transition tAnPro ("AnPro" stands for annual processing) is the one that consumes all of the 52 tokens (one for each week) and places them in pResult.

IV. SIMULATION RESULTS

Due to brevity, this paper does not present any implementation code. However, the complete code is available for inspection on the following website [25]. Also, the tool GPenSIM can be freely downloaded from the following website [26].

Data ("ROMS dataset") from Ocean Research Institute of Norway [27] and the data from [10] was fed into the model. Additionally, further information would have to be collected from the aquaculture industry in order to feed into the Neural Nets. However, the simulations took an unexpectedly long time. Unlike the analytical models, Petri net model behaves like a pipeline, as tokens have to travel from the sources (the places they are originated) to all the way to the sinks (the places the tokens finally settle). Also, the cycles in Petri net also makes the simulations very slow and in some cases termination of the simulation would not happen at all. Hence, the simulation time puts the Petri net modelling approach questionable to model this type of highly cyclic and repetitive systems. Hence, what we present in the section-V is a conceptual system or a template for a Petri net model for cost estimation Salmon Lice due to Global Warming.

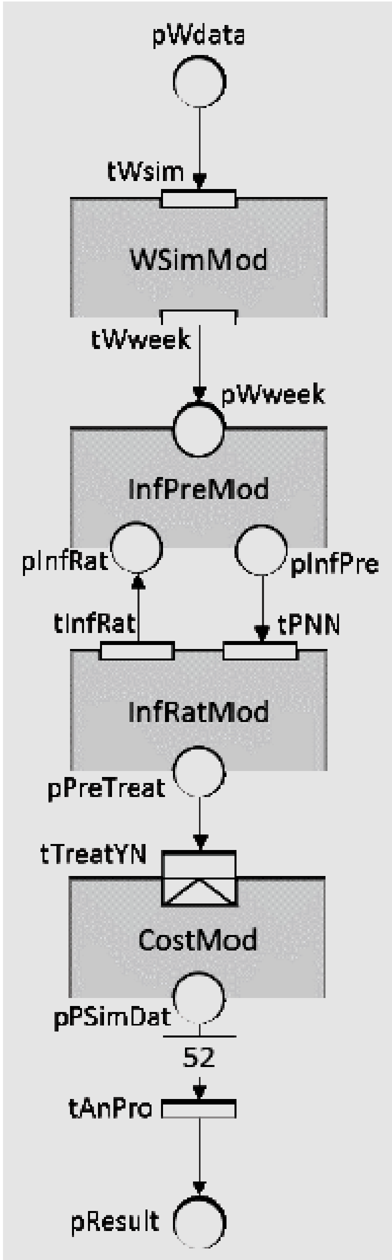

Fig. 7. The interaction between the modules.

V. DISCUSSION, CONCLUSION AND FUTURE WORK

Originality of this work: Literature study reveals no works done to find the direct economic impact of global warming on salmon aquaculture, by way of the effect on salmon lice. However, there are works done to indicate the general effect of global warming (e.g., [13]; [14]), or the economic impact of salmon lice (e.g., [28]; [3]; [4]).

Limitations of this paper: Being a conceptual model, this has been not verified. The test calculations were never compared with real data. Hence, the model presented in this paper should only taken for illustrative purposes. The model shows that it is possible to incorporate all the calculations as parts model - and this can be considered the benefit of this paper.

The subsections in section-III presented parts of the Petri net model as modules (Fig.3 - Fig.7). However, these modules do not strictly follow the definition of Petri modules presented in [29] and [30]. Hence, some work is needed to re-work these modules into proper modules.

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