Operational Risk Management in Aquaculture

Benjamin S. Narum, Julio C. Goez and Stein W. Wallace
NHH Norwegian School of Economics

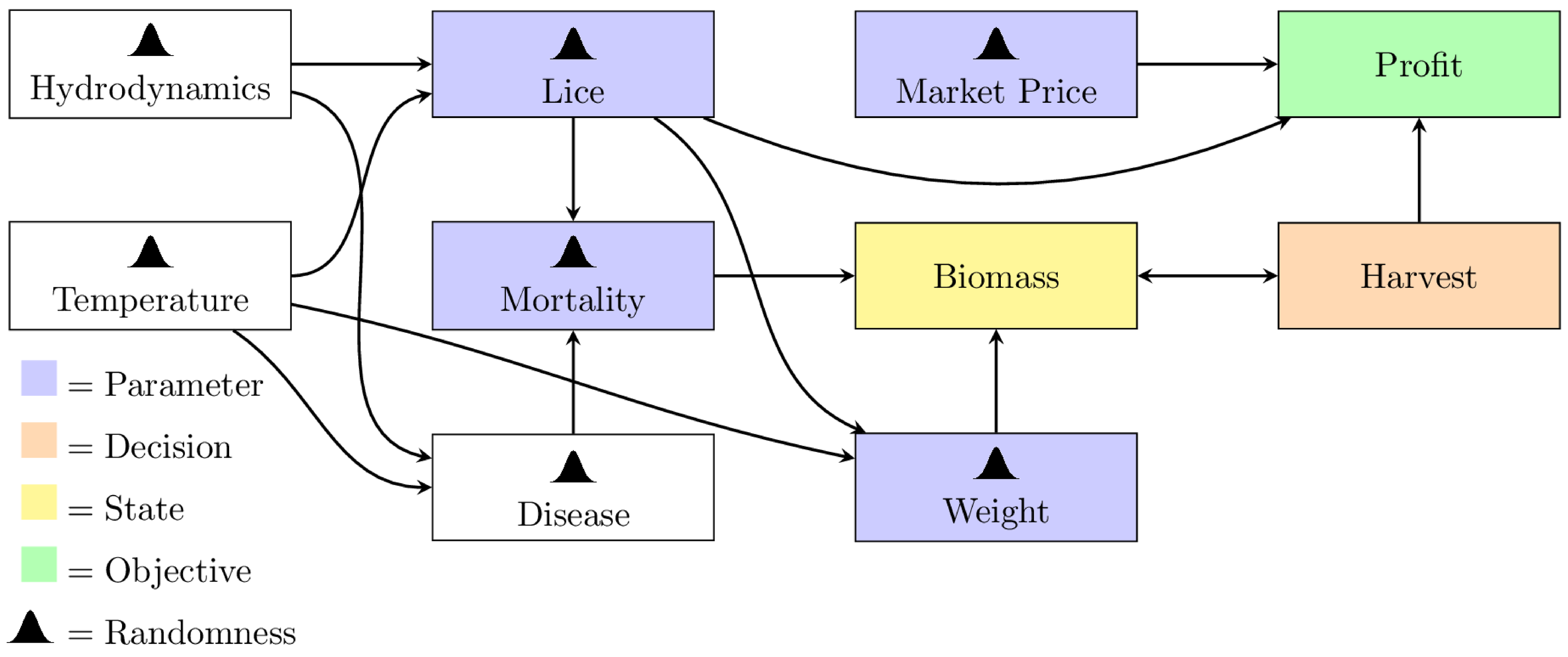
Problem statement

Aquaculture operations is characterised by ***large risk exposure*** in a ***complex environment*** to decide ***when and where to harvest*** within a ***portfolio of sites***. The complexity of this problem makes it appropriate for application of quantitative risk management models.

The fundamental complicating factors are:

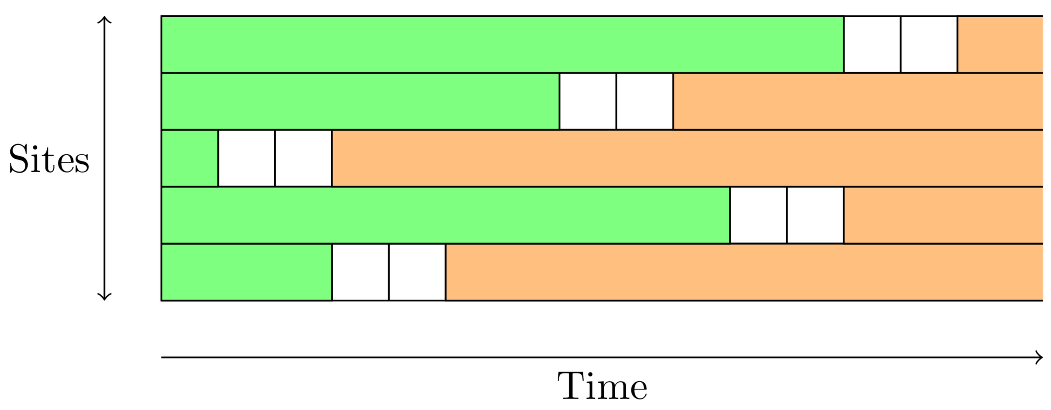
- Biological risk
- Market volatility
- Regulatory constraints on operations

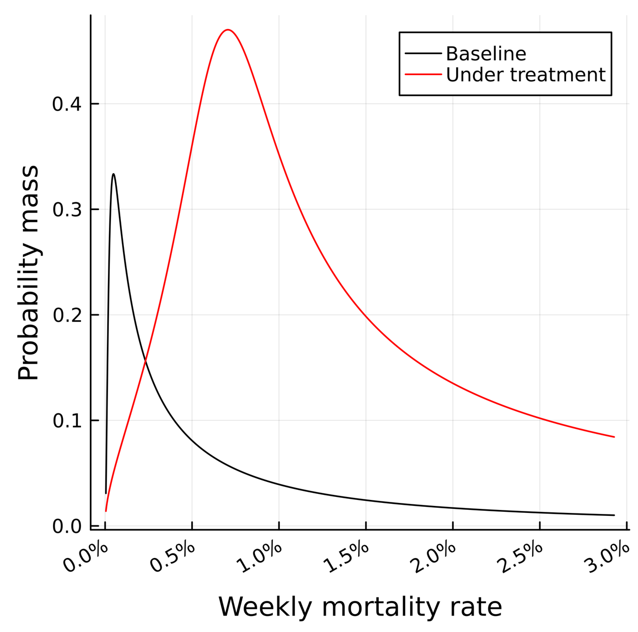
A fundamental source of biological risk is that the fish stock is exposed to a ***stochastic surrounding environment***, whose factors of primary importance are temperature, disease and parasitic lice development. These contribute to the health state and growth of fish. Additionally, ***spot prices are highly volatile*** which makes short-term timing of harvests profitable, while there are limiting ***regulatory constraints on the maximum total biomass***. Lastly, farmers have large capital allocations in standing biomass, making them vulnerable to large and unforeseen losses.



Modelling assumptions

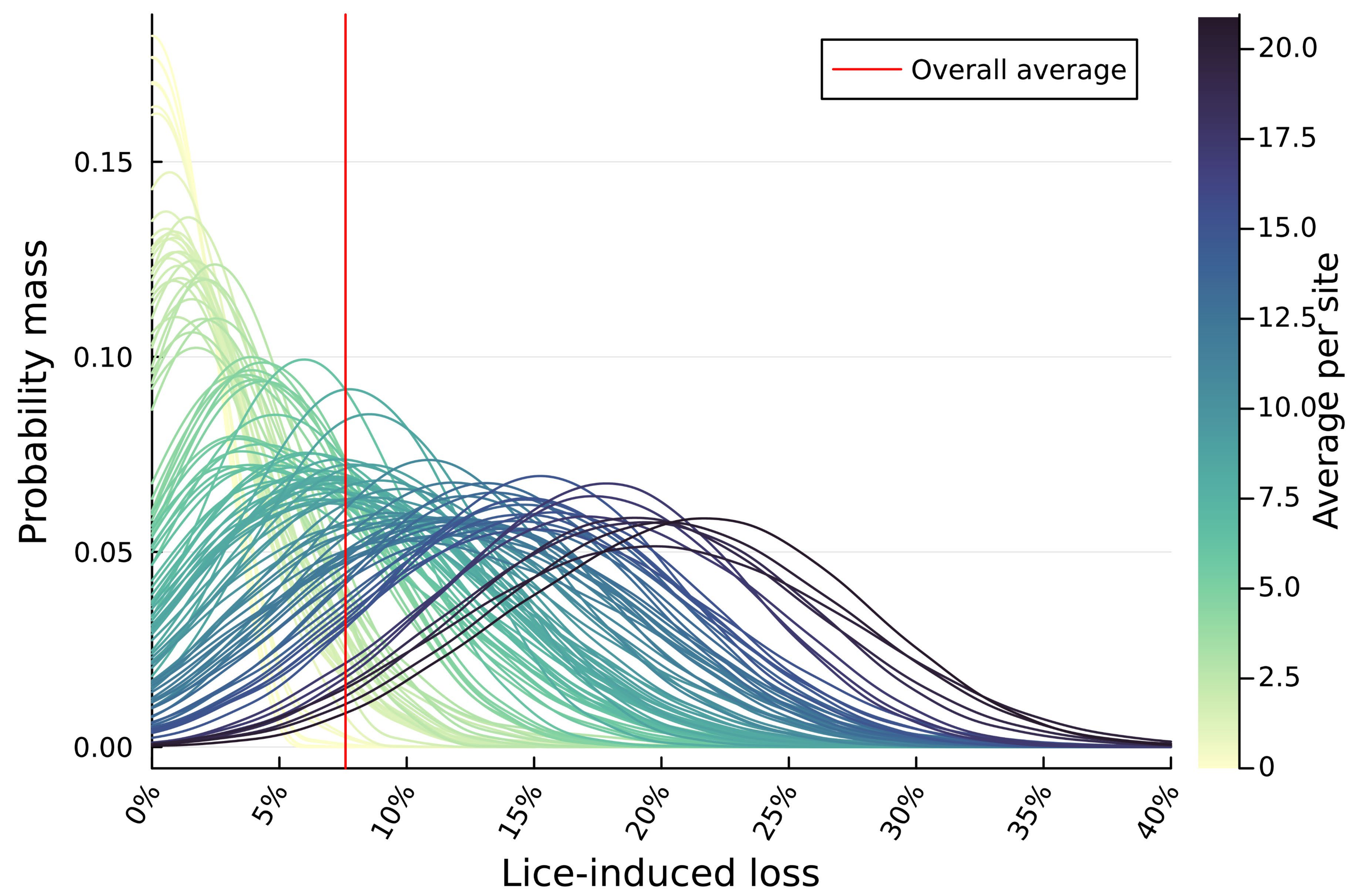
We formulate a ***Multistage Stochastic Programming*** problem to in a ***rolling horizon environment*** to manage harvest schedules of ***currently open sites*** until they are re-stocked. The ***lump cost*** of well-boat orders are encoded by decision variables in the range $\{0\} \cup [1, \infty)$ to reduce combinatorial complexity and strengthened by tightening constraints. Treatment for parasitic lice is ***modelled as an exogenous stochastic process*** since it is mainly governed by the state of lice abundance, which also avoids decision-dependent uncertainty.





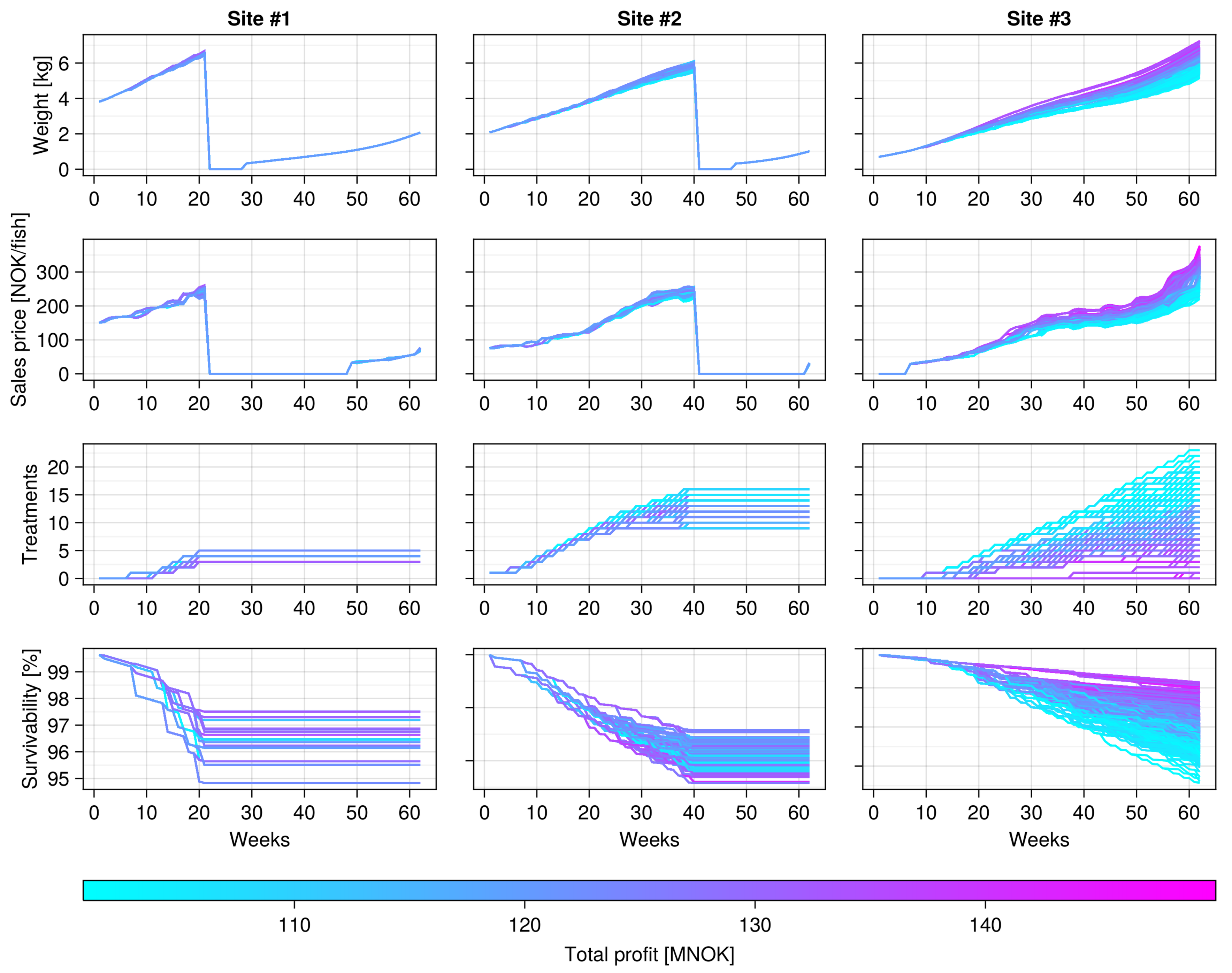
Biological risk

Biological risk is governed by the health state of fish, which is primarily affected by ***exposure to lice treatment*** (which harsh on the fish) and ***occurrence of disease,*** which are ***density-driven spatial-temporal phenomena***. Treatment is a significant driver of operational cost, biological risk and mortality, and is governed by regulatory requirements on the level of lice abundance. We model lice abundance and treatments as interacting stochastic processes to derive a ***forecasting distribution for future lice-induced losses across sites***. The distribution of mortality rates is derived conditional on lice treatment, whose upper tail represent increased mortality due to disease.



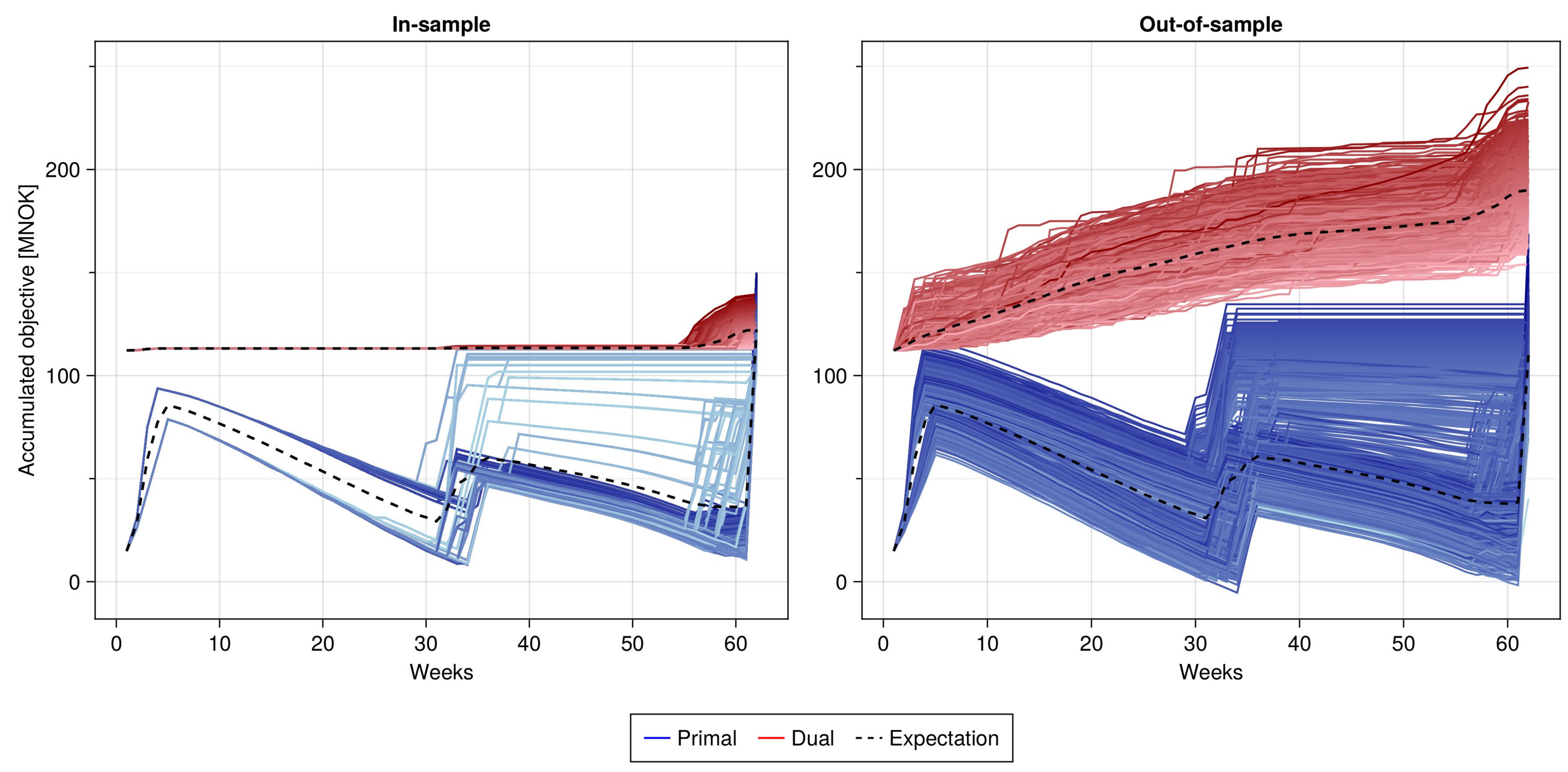
Representation of uncertainty

Uncertainty is represented by a ***discrete scenario tree*** on which the optimised decision policy is defined. The scenario tree represents the underlying stochastic process and should provide effective decision policies. Ideally, the scenario tree should capture both important ***short-term volatility*** (price and mortality) and ***long-term development*** (growth and health) to replicate how these affect decisions.



Validation of scenario tree policies

We ***validate the scenario tree policy*** on ***out-of-sample*** outcome paths to find ***bounds on its real effectiveness***. The lower bound uses an extension policy to validate the realised profit if the tree-based policy was implemented. The upper bound is correspondingly derived from a dual extension policy and represents excess available profit.



Risk exposure – Volatility in profit

Risk exposure in aquaculture operations can be interpreted from the volatility in profit within the operational model. We conclude there is ***large variability in profit,*** which means there is considerable operational risk that is also difficult to hedge. As expected, in-sample policies are optimistic; hence, we also benchmark using out-of-sample realisations to get more realistic estimates.