

# *The Utility of System Dynamics Analysis For Managing Lake Sustainability*

NH Lakes Management Advisory Committee  
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New Hampshire DES  
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# *Presentation Outline*

- Define SDA
- Explain utility in understanding and managing lake carrying capacity
- Summarize value added for making decisions to optimize strategies



# *System Dynamics Analysis (SDA)*

- Innovative approach to evaluate complex problems where factors affecting output are interconnected and change with time
- Methodology that addresses the complex interactions that may lead to unintended consequences and counter-intuitive behavior, simultaneously managing continuous and discontinuous relationships
- Capable of evaluating how systems will behave as a result of change, be it due to decided actions or uncontrolled events.



# ***Challenge – Justification for SDA***

- Need to optimize environmental risk management strategies
- Strategy must properly plan and sequence activities to be:
  - Cost and time effective
  - Protective of natural resources
  - Satisfactory to users and non-users of lake



# *Challenge – Justification for SDA*

- 1) **Optimize** (not maximize) the user's lake experience!
- 2) Uses of lake(s) surfaces should be regulated to maintain compatibility among users without degrading lake resources!!!

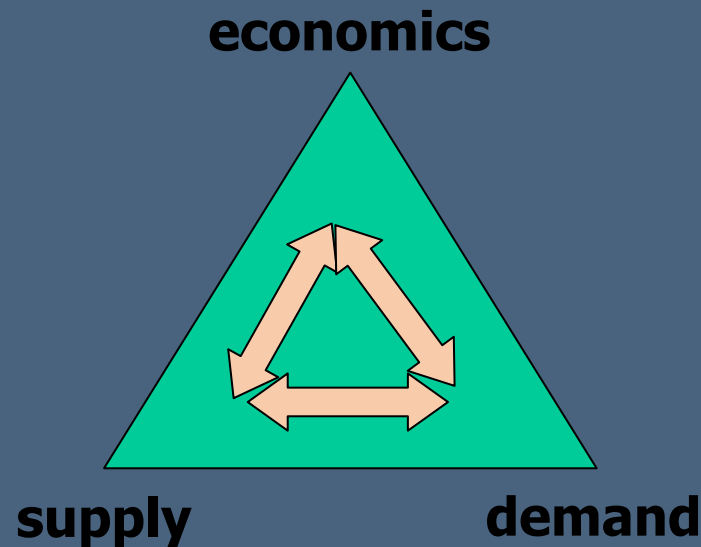


# What Are Systems?

- Systems are networks of positive and negative feedbacks
  - Everything is connected to everything else
  - You can't "just do one thing"
  - Unintended consequences and counter-intuitive behavior
- Systems are dynamic because feedbacks interact
  - Nonlinear feedback dynamics
  - Positive feedback: Self-reinforcing, i.e., amplify trends in place
  - Balancing feedback: Self-correcting, i.e., oppose change
  - Causal tracing maps system behavior
- Feedback captures learning, changing future behavior



# *Simple Yet Complex System of Cause and Effect*



# *What SDA Offers*

- Single platform for decision-making
  - Common basis for analysis and choice
  - Integrated consequences
  - Unintended consequences
- Helps decision makers make complicated decisions
  - Multiple options, in series or together
  - Affordability
  - Resource sustainability
  - Capital improvement
- Provides basis for consistent risk communication





# *Level of Effort Required*

**ADAPTABLE TO SCALE OF INTEREST  
AND REQUESTED LEVEL OF EFFORT**



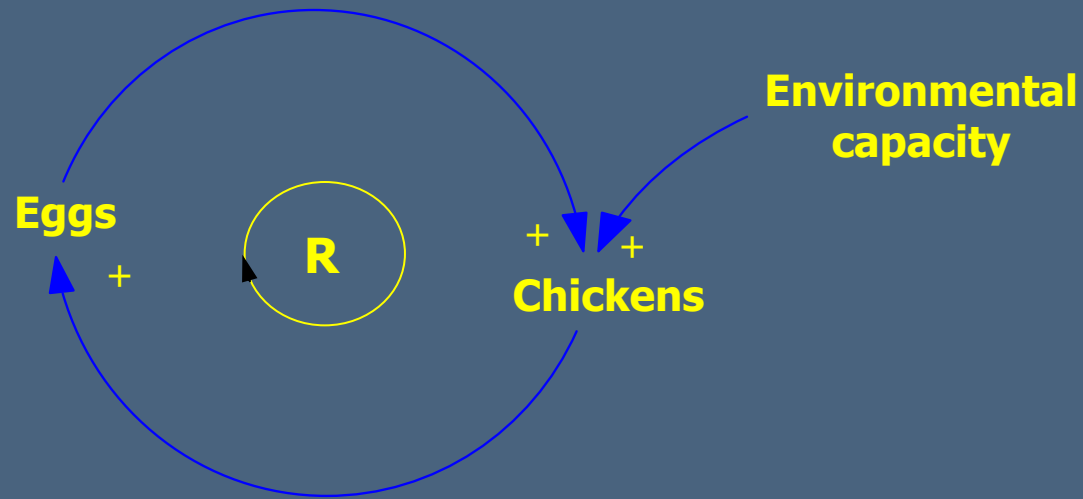
# *Justification to Use SDA*

- Provide insight into a problem
- Develop innovative solutions
- Optimize strategies

**CLIENTS INVEST IN SDA WHEN THEY WANT TO BETTER UNDERSTAND AND ACHIEVE THE BEST POSSIBLE RETURN ON THEIR INVESTMENT OR PROTECTION OF ASSETS**



# *Chickens and Egg Example*



*This is a REINFORCING feedback loop*

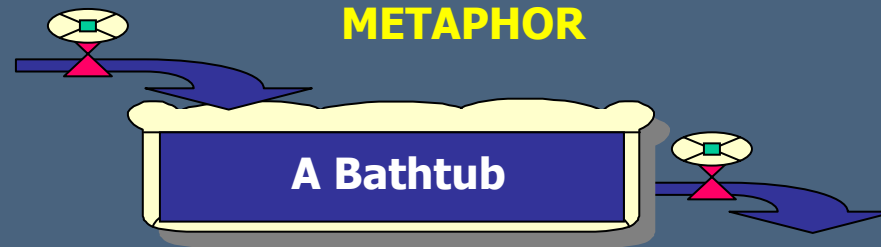


# SDA Approach

- Functional relationships
  - Constants
  - Equations
  - Tabular input
  - Graphical interpretations of a relationship
- Definitions of each functional relationship are based on
  - Field characterization data if available
  - Otherwise it is based on hypothetical data that is consistent with those presented in the literature
- Model development and analyses proceed iteratively, refining the model with increasing knowledge of the system
- Sensitivity analyses for the communication and defense of choices to stakeholders



# Building Blocks for Analysis: Stock & Flow



## STOCK & FLOW DIAGRAM



## DIFFERENTIAL EQUATION

$$d(\text{Stock})/dt = \text{Net Change in Stock} = \text{Inflow}(t) - \text{Outflow}(t)$$

From Sterman, 2001



# *Stock and Flow Formulation*

- Mass balance
- Take derivatives with time
- Continuity, chain rule, and rearranging
- Constraints, e.g., equilibrium
- Solve for flows, i.e., fluxes



# ***SDA for Lake Capacity Management***

- Aquatic ecosystems are complex systems, with networks of positive and negative feedback loops
- Each management decision may directly an/or indirectly affect several parameters, comprehensively driving, for better or worse, the ecological integrity and sustainability of the lake for its intended use
- SDA needed to understand and predict consequences of management options to optimize outcomes



# *Multiple Complexities of Carrying Capacity*

- Ecological System
- Sociological Phenomenon
- Human and Watershed Development



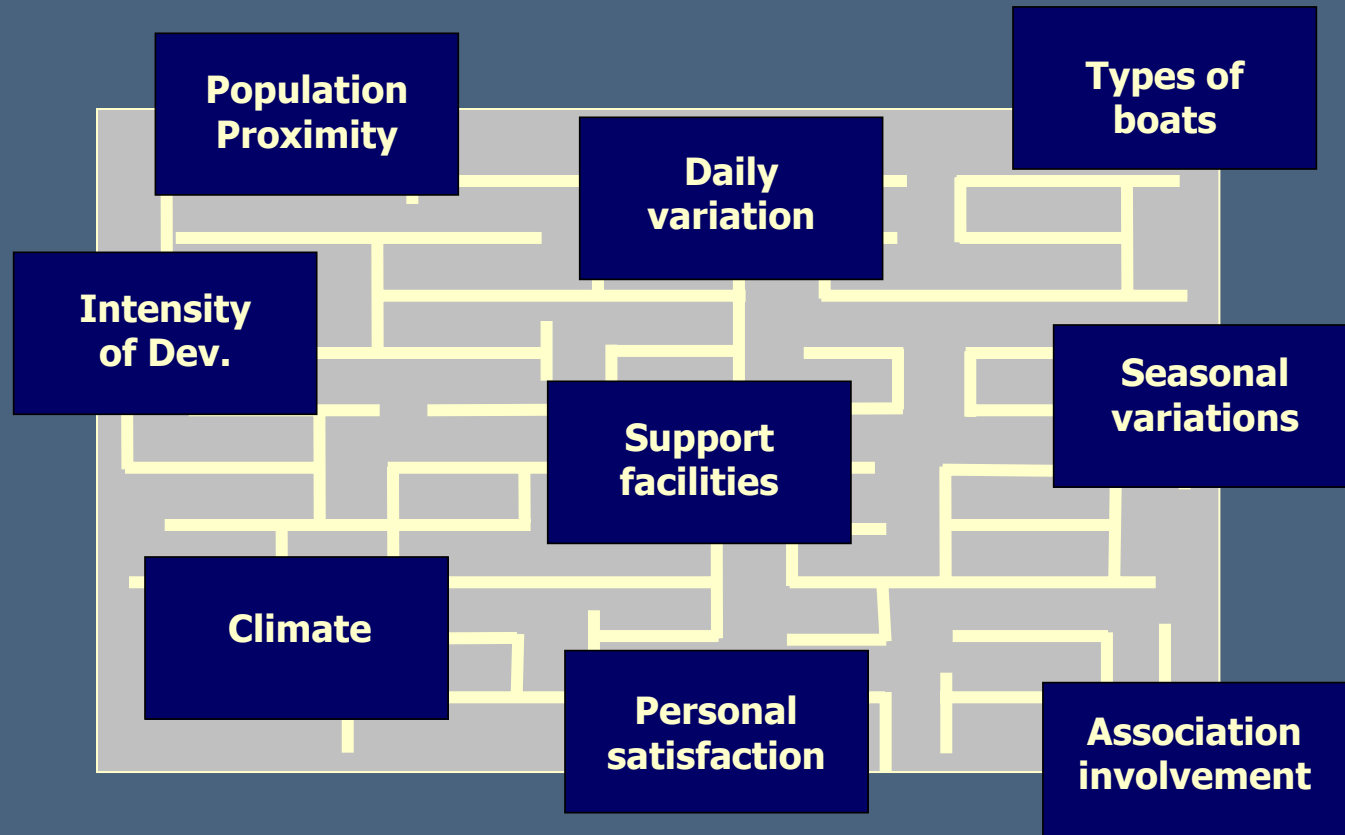


# *Carrying Capacity Management Tools*

- **Spatial** - limit use(s) to certain lakes or portions of lakes
- **Time** - limit use(s) to time of day and/or day of the week
- **Activity** - limit use to certain lakes and/or portion of lakes (zones)
- **Horsepower limits**



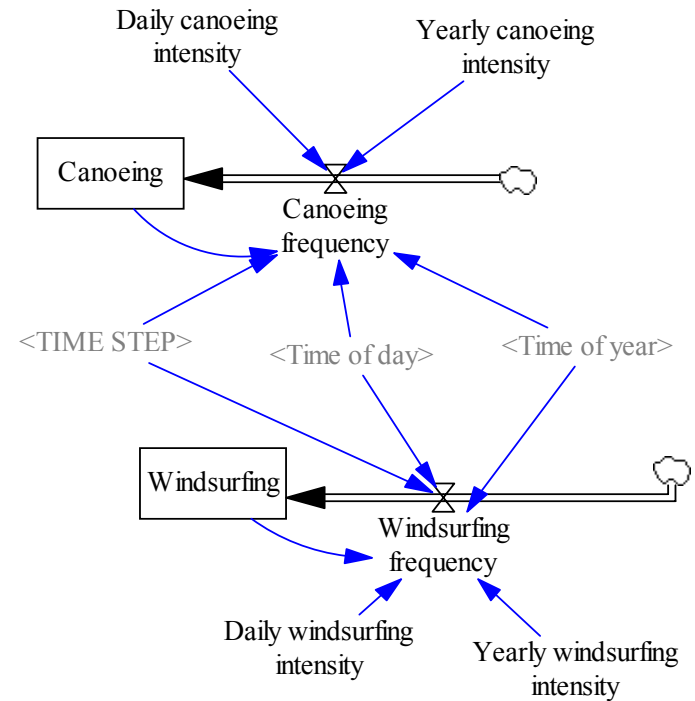
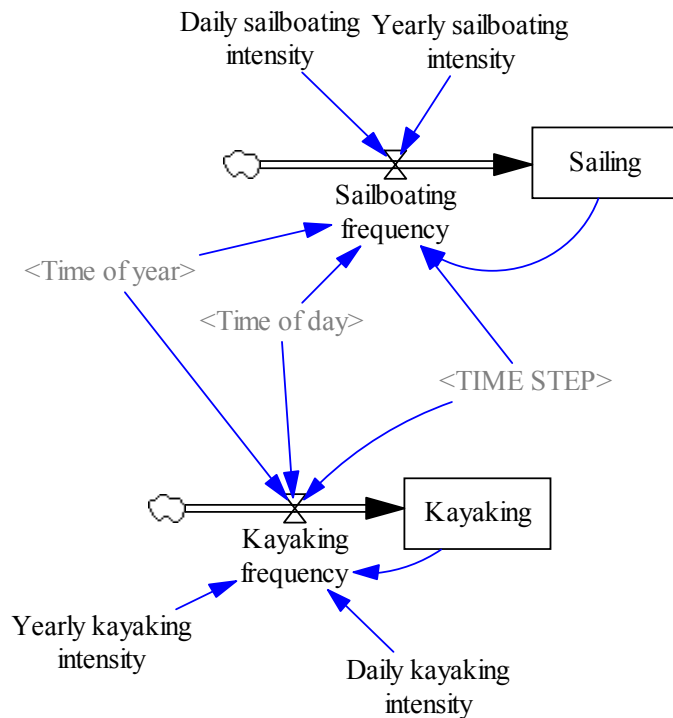
# *Multiple Factors/Decisions/Events Challenges Intuition*



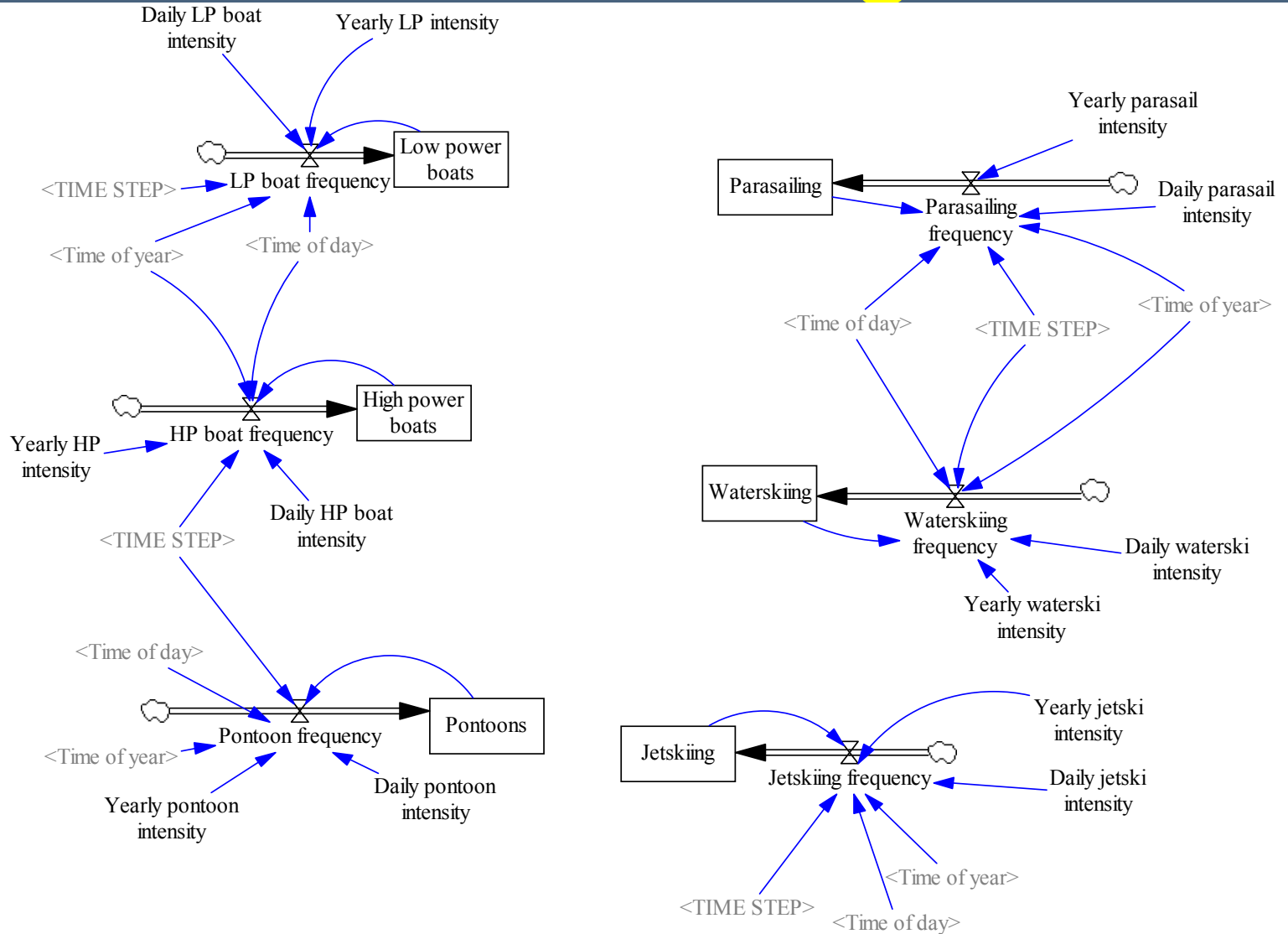
*Dynamic modeling provides for consistent decision process*



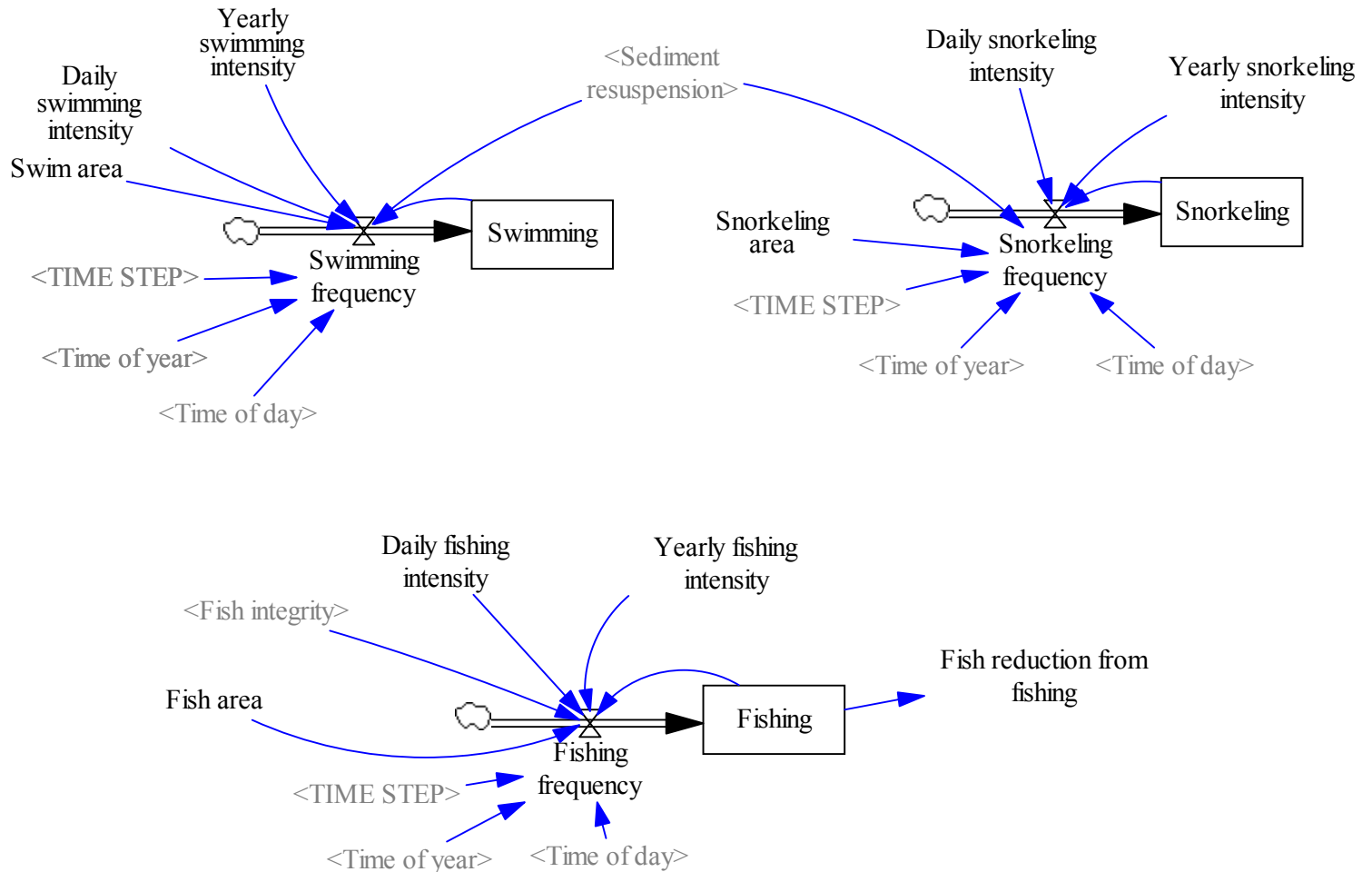
# Stock and Flow – Non-Powered Boating



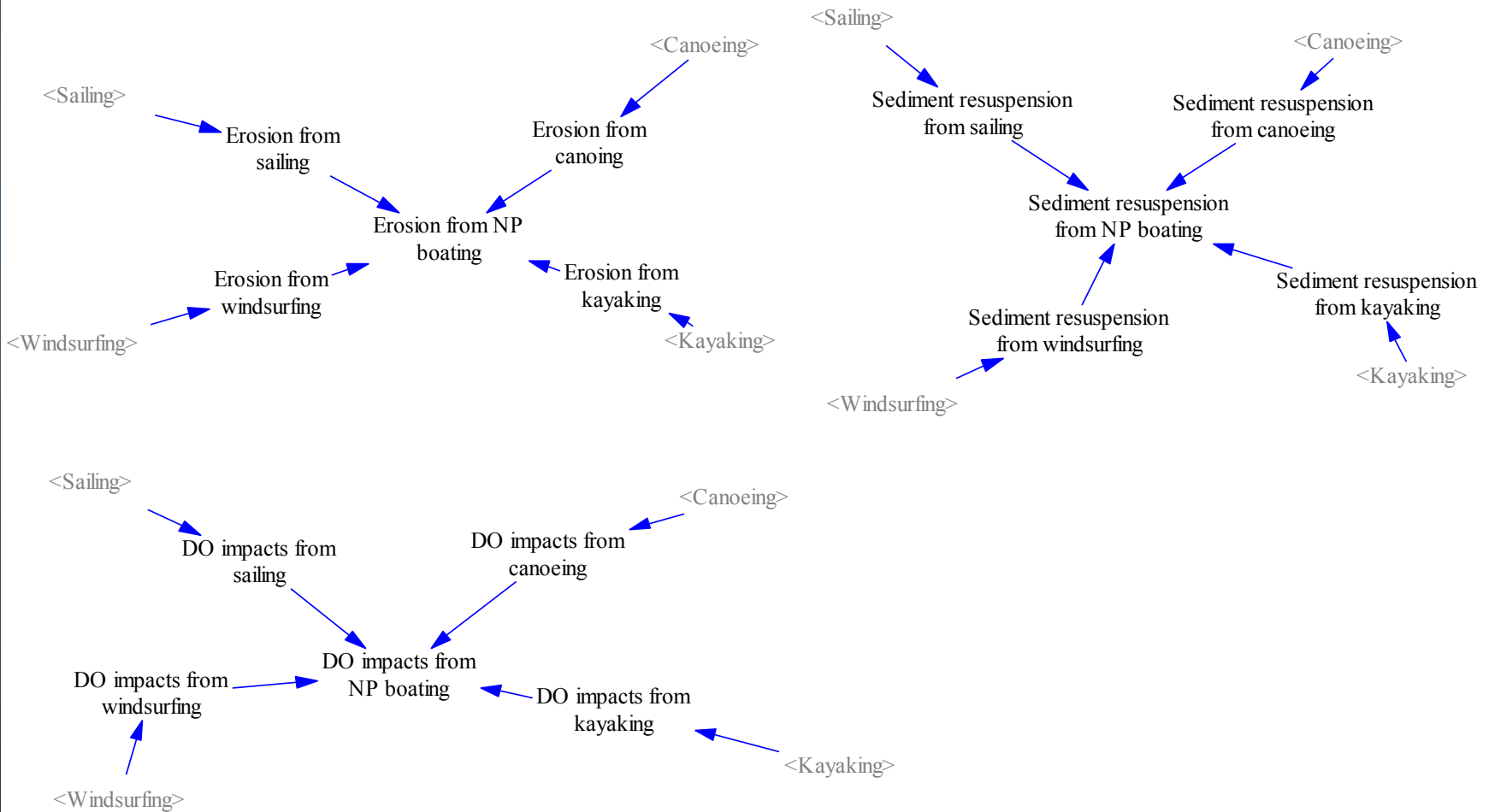
# Stock and Flow – Powered Boating



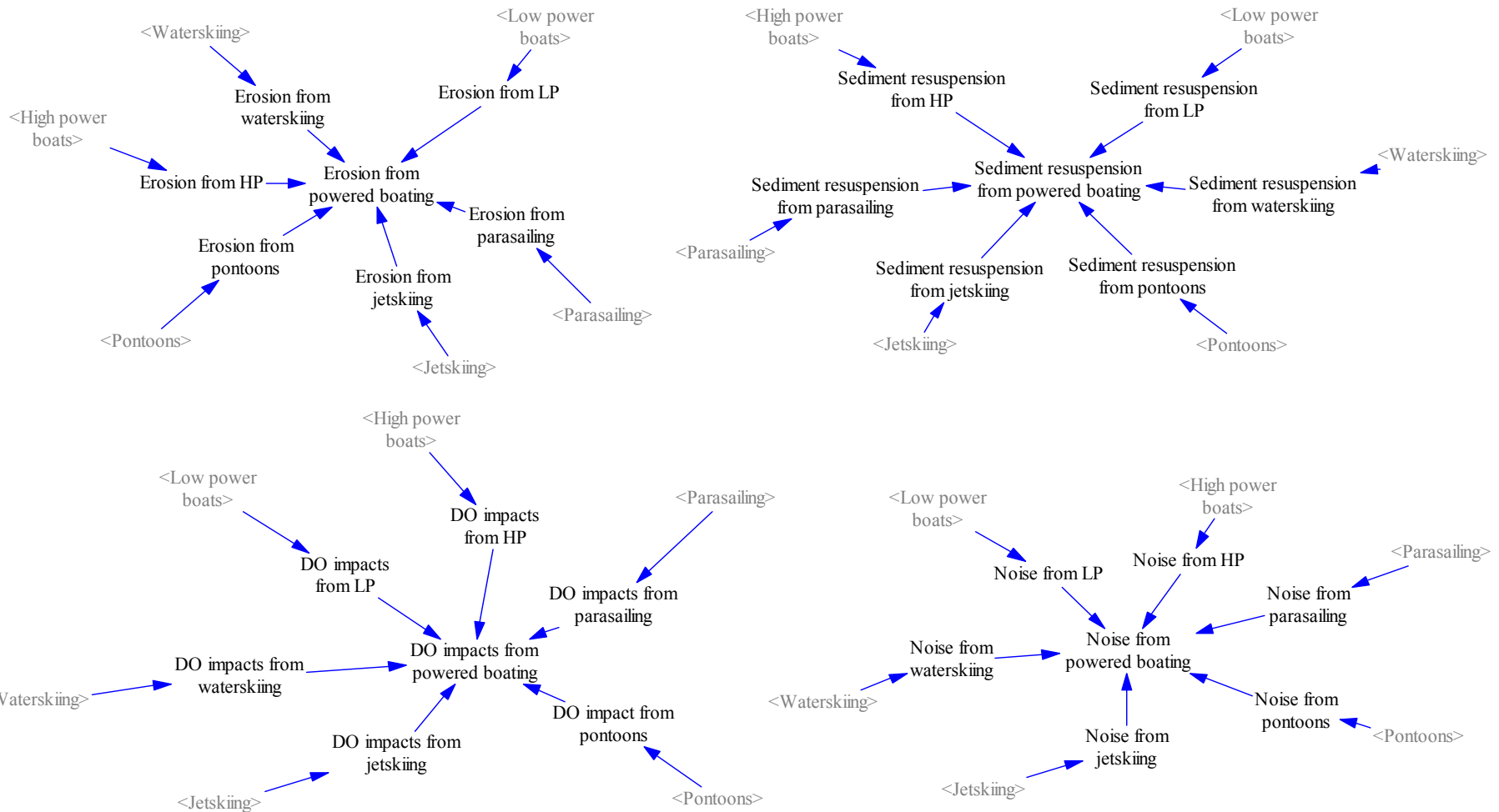
# Stock and Flow – Individuals' Activities



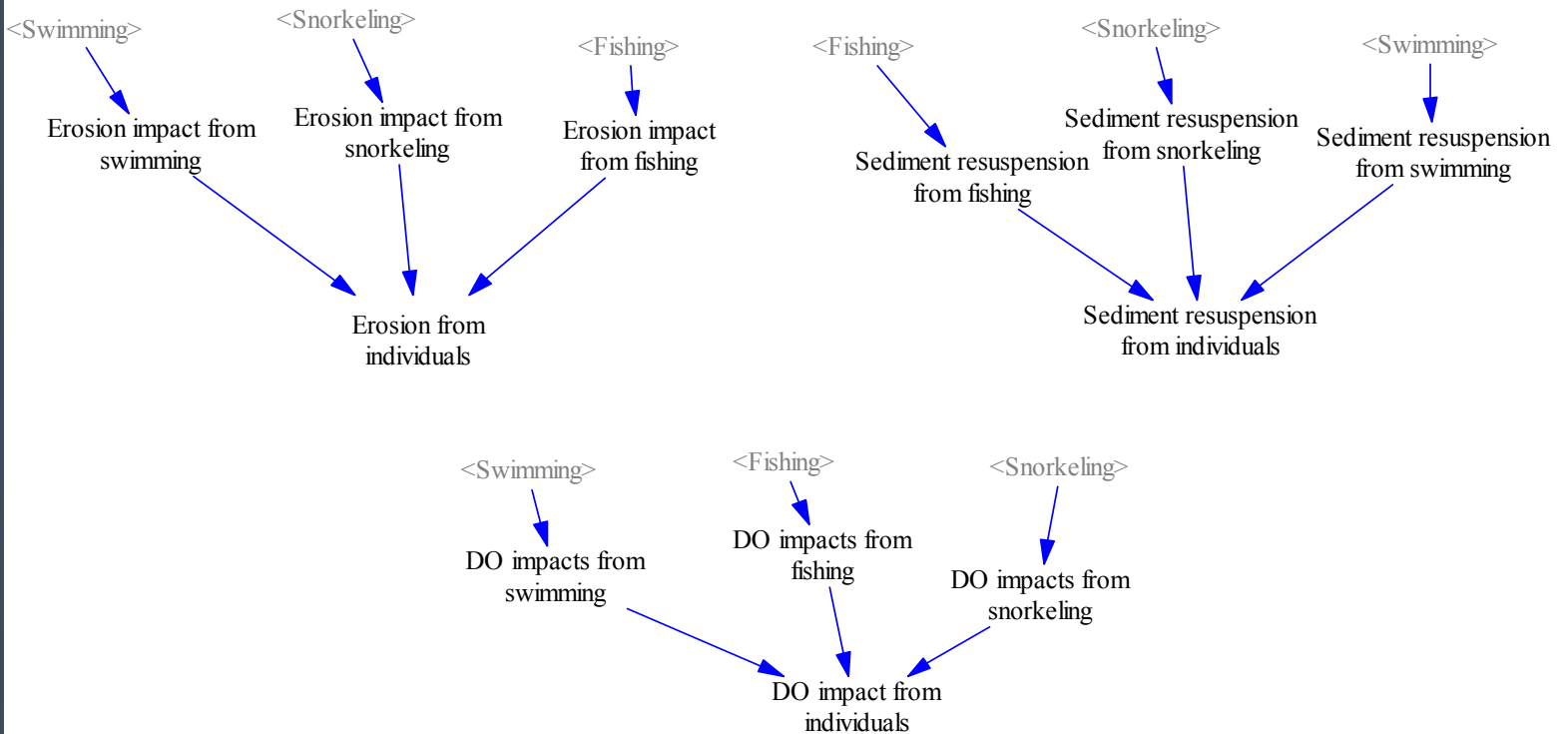
# Stock and Flow – Non-Powered Boat Impacts



# Stock and Flow – Powered Boat Impacts

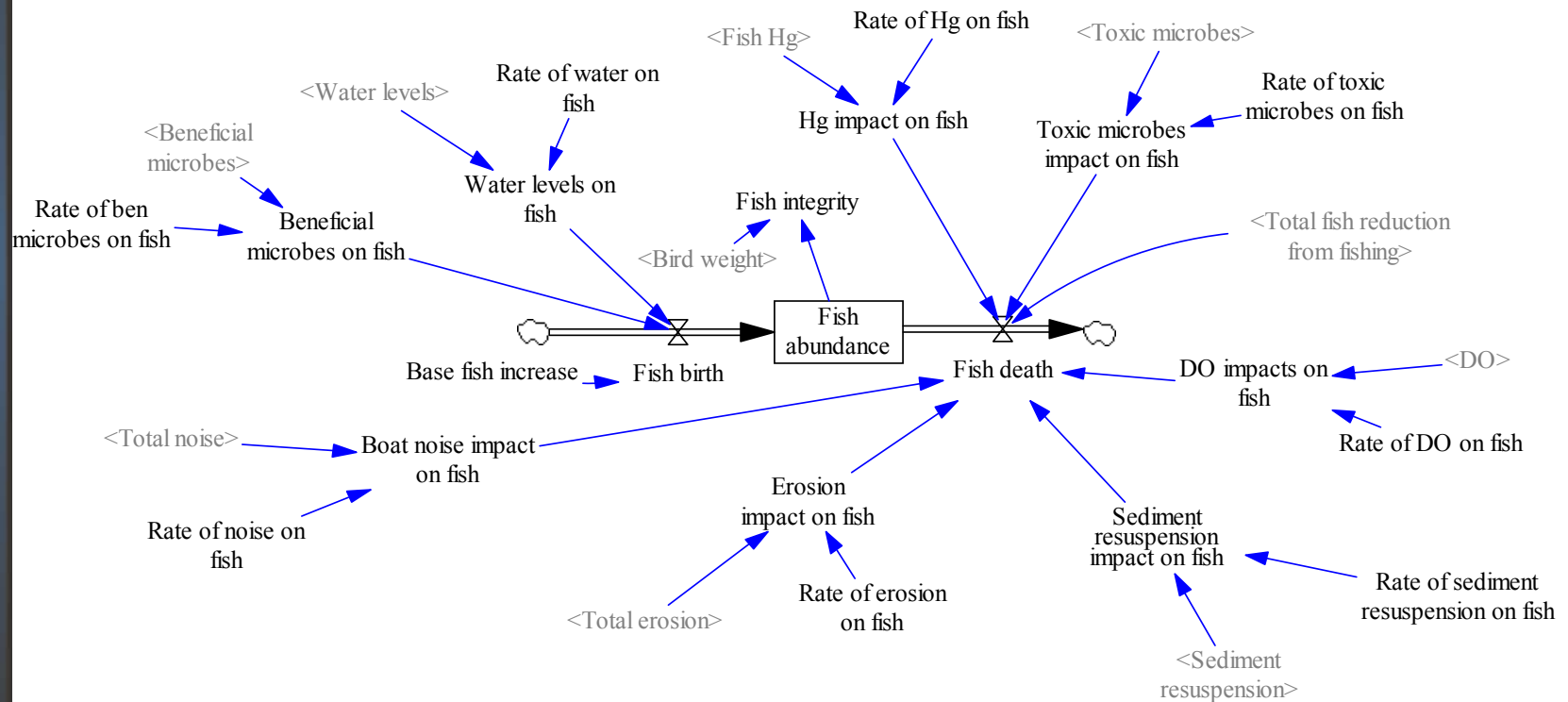


# Stock and Flow – Individuals' Impacts

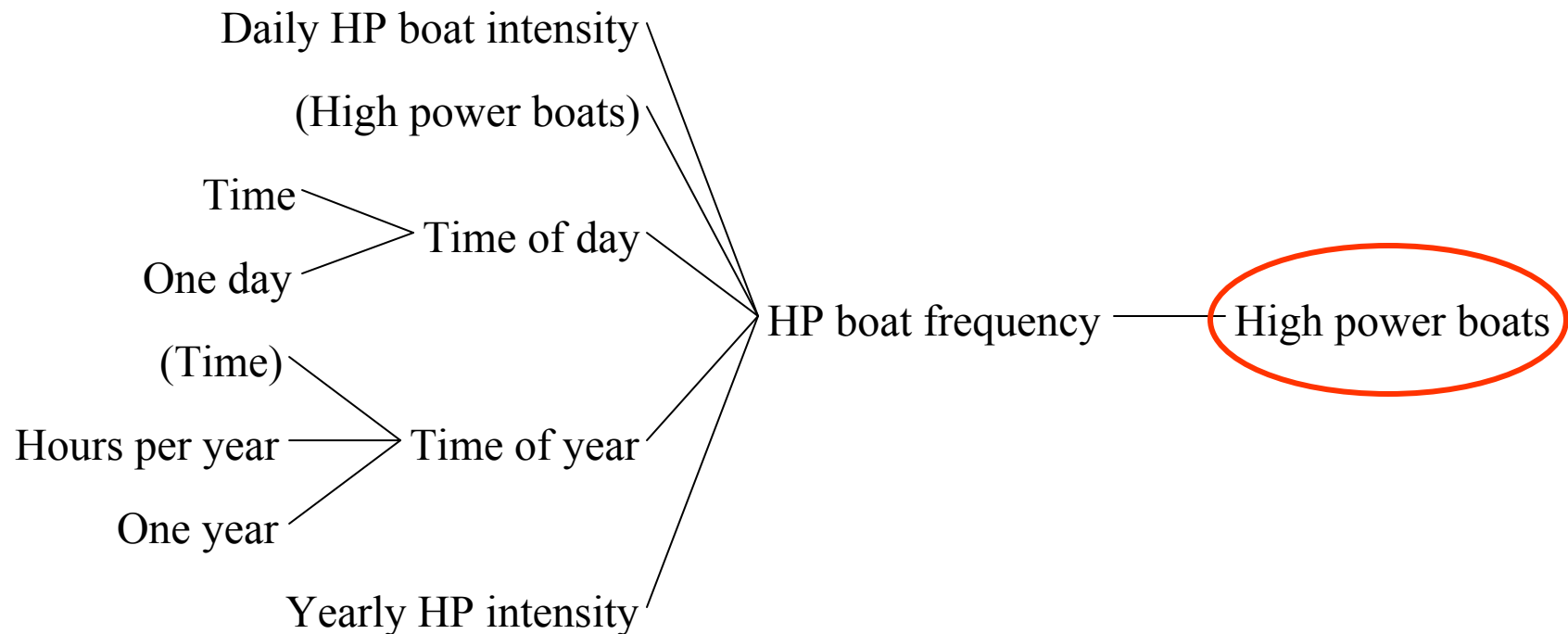




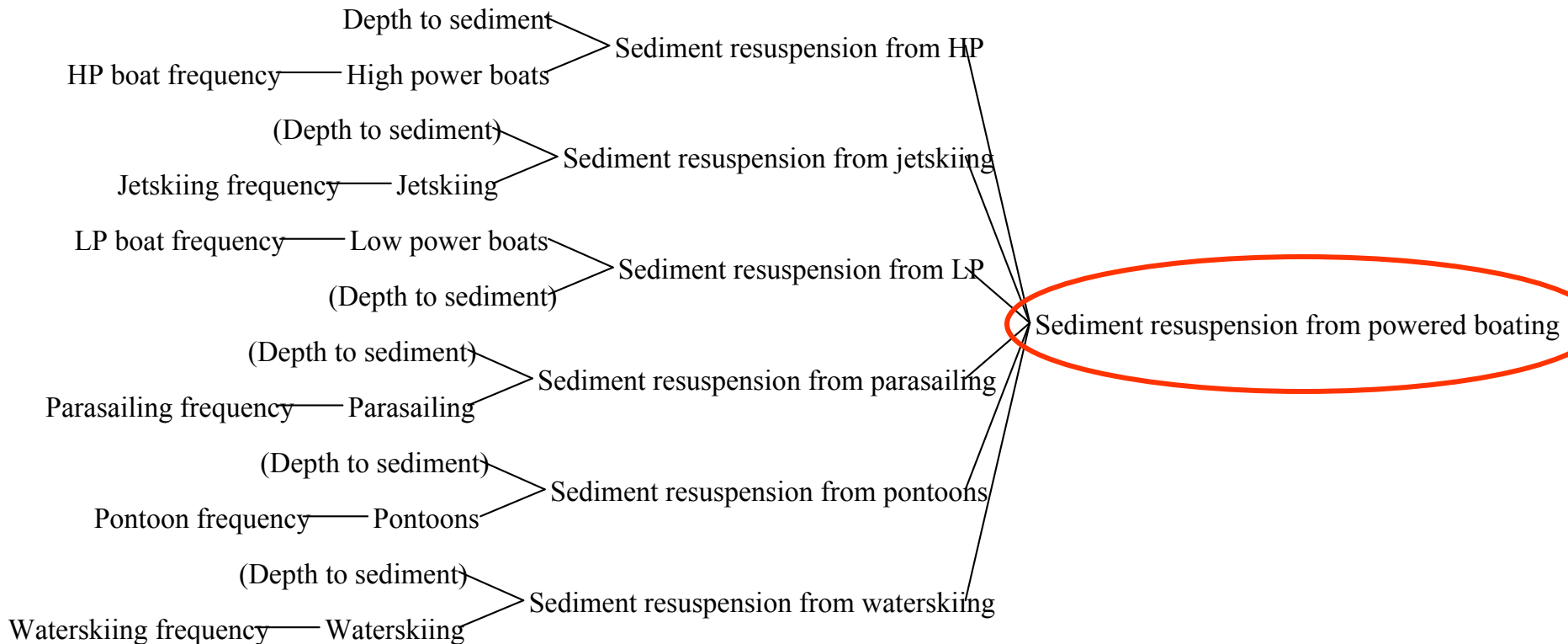
# Stock and Flow - Fish Integrity



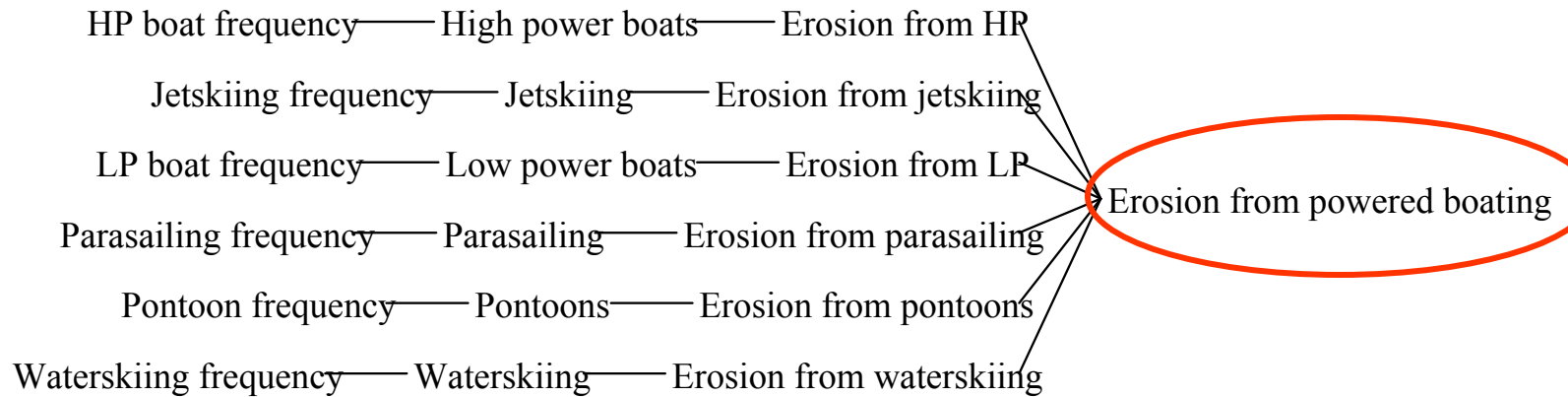
# Causes Tree – High Powered Boats

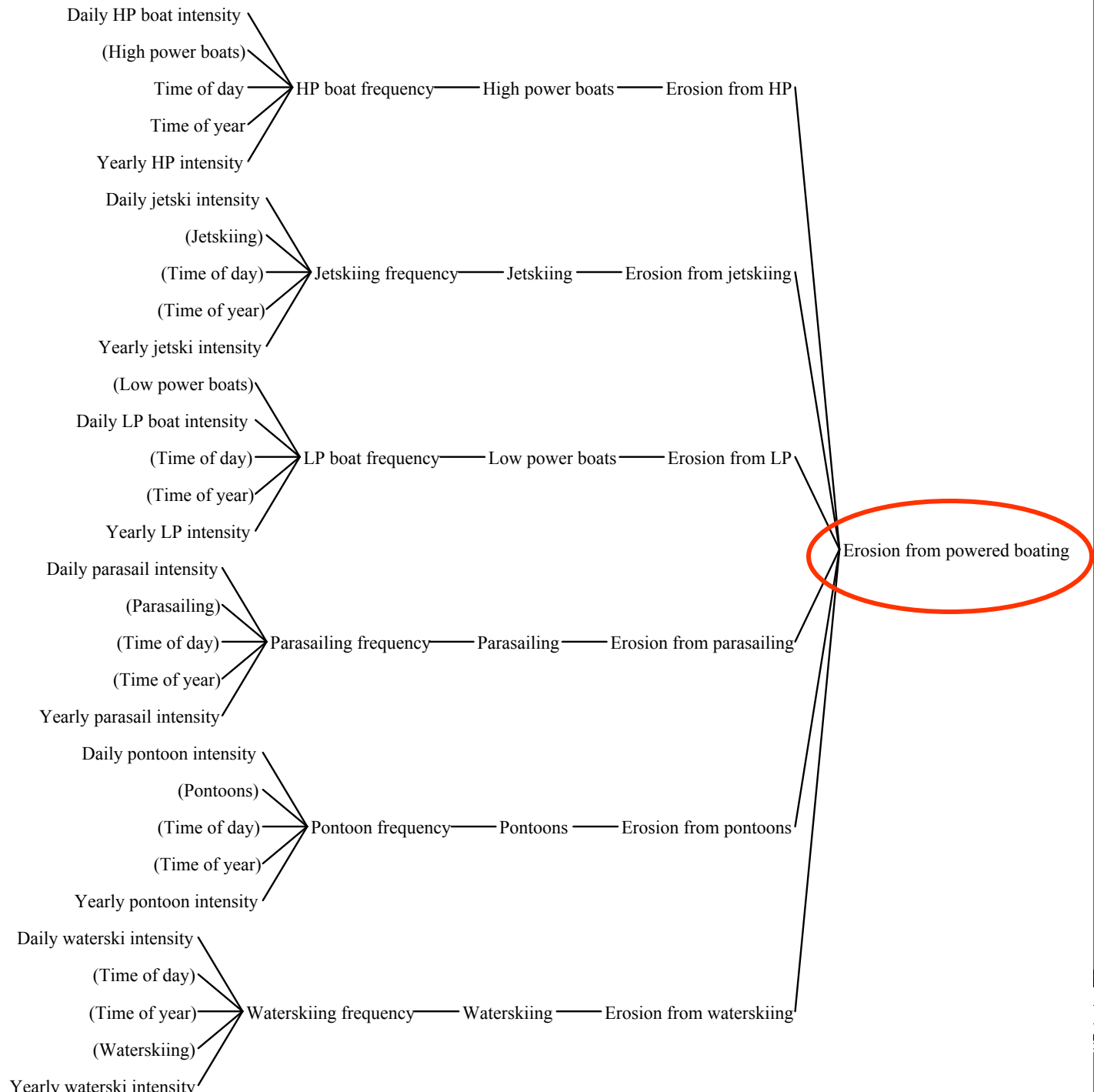


# Sediment Resuspension from Powered Boats



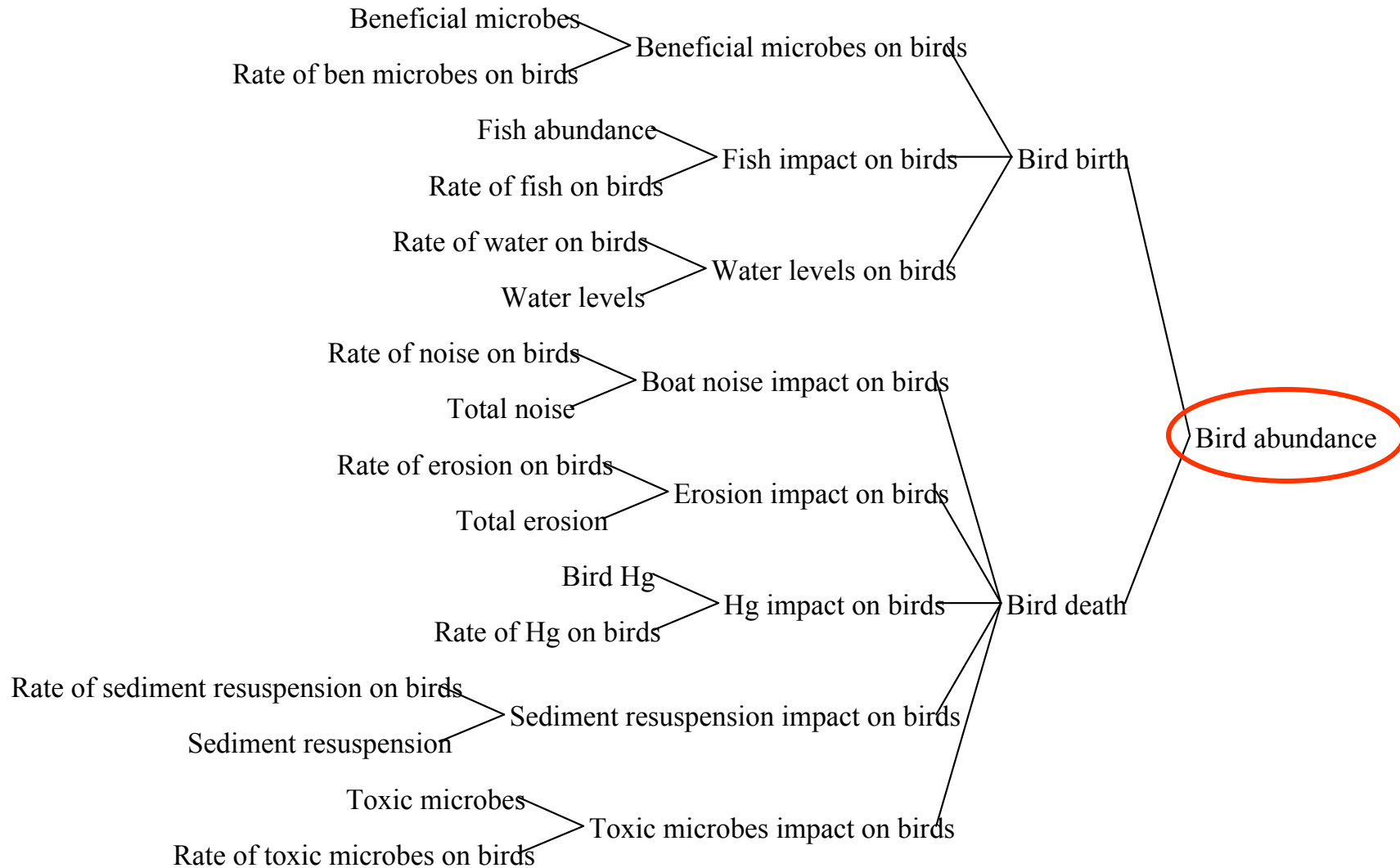
# Erosion from Powered Boats





# Biological Indicators

## Bird Abundance



# *Justification to Use SDA*

- Exceeds DECISION RISK ANALYSIS (DRA)
  - Feedback
  - Details
  - Active analysis
- Logical and visual
- State of the art
- Dynamic
- Any metric
- Advanced math not needed ...but applied
- Scenarios and long term impact

