Industrial Engineering Tools for Building Biorepositories

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part of the Coral Restoration Consortium

Introduction

Research to cryopreserve aquatic species was first conducted more than 70 years ago, and since then, research on "protocol development" has been performed on well over 200 species (Yang & Tiersch, 2009). However, despite this history of cryopreservation research, biorepositories are not widely used in aquaculture industries or aquatic species conservation efforts (Martínez-Páramo et al., 2017; Yang et al., 2021; Yang & Tiersch, 2009). There is a disconnect between developing research-level cryopreservation protocols for a species and implementing cryopreservation and repository storage on a larger community scale. Challenges for the implementation of cryopreservation protocols include a lack of reproducibility, generalizability, and scalability. For example, protocols developed at one research laboratory for a specific species are often not transferable to other facilities (lack of reproducibility), other species (lack of generalizability), or effectively applied to community-level efforts (lack of scalability) (Bodenstein et al., 2023; Hu et al., 2013).

Furthermore, cryopreservation is just one part of the greater biorepository collection process. Samples must be identified, collected, and properly cataloged in a database before cryopreservation. Additionally, standardized procedures must be established to store, locate, disseminate, and reconstitute samples after cryopreservation. For biorepository development in coral and other aquatic species to be successful, tools from other fields, such as industrial engineering, must be applied. These tools can support interdisciplinary work that advances and standardizes research-level cryopreservation protocols and other biorepository collection activities into community-scale biorepository pathways.

Relationship Diagrams

Relationship diagrams are useful industrial engineering tools to begin analyzing the coral restoration community. Relationship diagrams depict the interactions between different members of a network or community, as well as the flow of materials and information among those members (Damelio, 2011). These diagrams can be used to highlight how each community member contributes to the greater network and how biorepository facilities must operate to meet the needs of the community. To begin constructing a relation diagram, first, the major members of a network and any central group or resource (the network hub) with which all members interact must be identified. Next, the primary roles or functions of each member and the network hub (i.e., providing coral samples, freezing samples, genetic research, writing policy) are listed. Members and the network hub are visually displayed on the diagram. Interactions between members and the hub and among members are drawn on the diagram based on the identified major activities. Finally, if the diagram is intended to track a specific resource, such as biorepository samples, unique symbols can highlight where the resource is produced and stored, as well as how it moves through the network.

In Figure 1, a relationship diagram was created to display how the major coral community members interact with coral reefs (the network hub) and with each other. This diagram was built to represent generalized groups and interactions on an international scale. In addition to the network hub (coral reefs), five major community members were identified: Research Facilities, Regulatory Agencies, Tourism, Fisheries, & Aquaculture, Biorepositories, and Restorationists & Conservationists. This diagram was intended to highlight how biorepository samples interact with the coral community, so four unique symbols were included to encompass the major types of samples. Cryopreserved Samples, generally referring to frozen gametes, are frozen in such a way that they can be thawed and used to reconstitute a coral genome. Frozen Samples, generally referring to frozen tissue, can be thawed for genomic analysis but not to reconstitute a genome. Live Coral and Live Symbiont samples are living coral or symbionts kept in "live biorepositories". Evaluation of Figure 1 can reveal patterns in coral community function, highlight gaps in that function, and assist in developing community goals. Understanding how a network or community functions is imperative in building a sustainable system that can meet the network's goals.

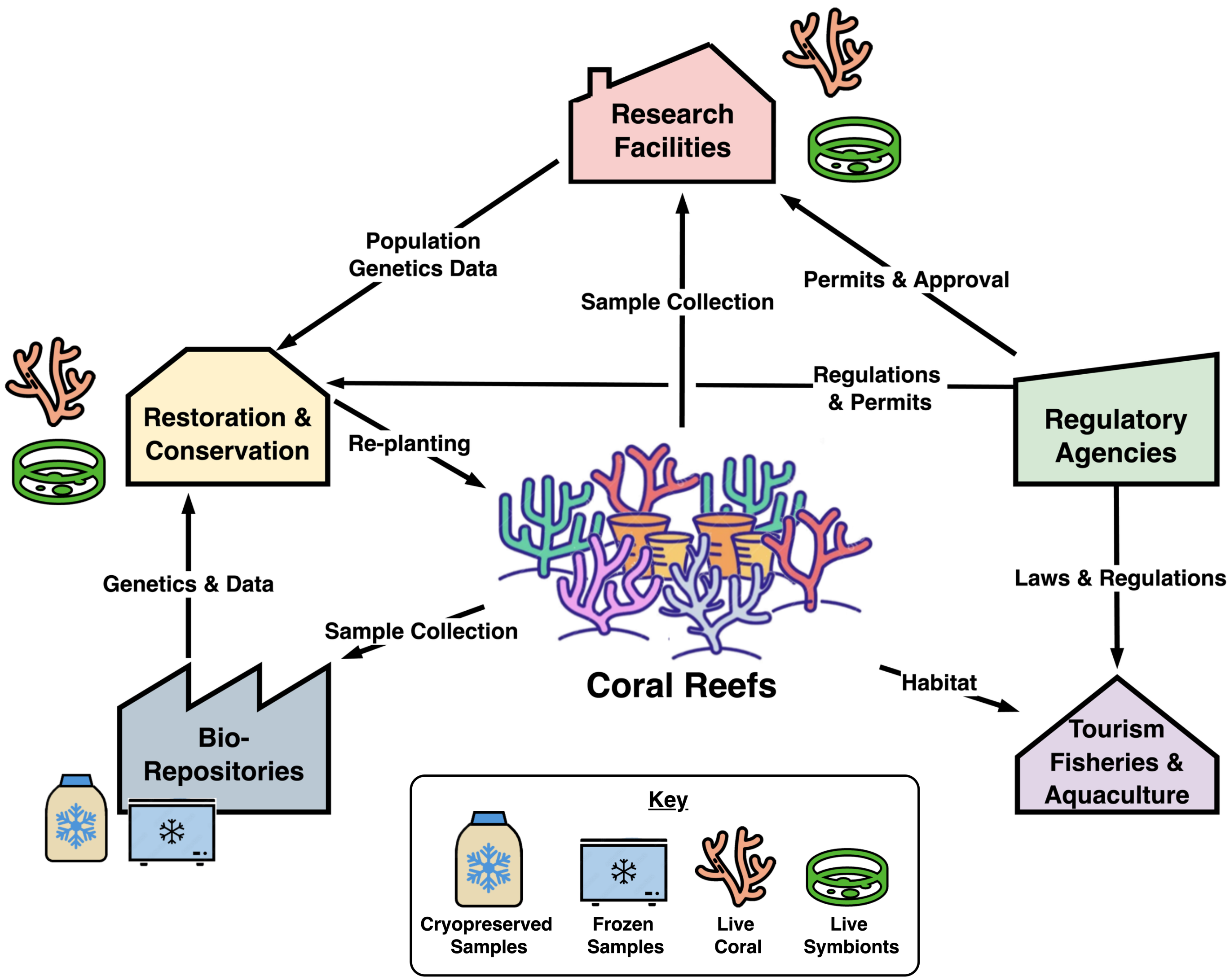

Figure 1. *A network-level relationship diagram that displays how the major coral community groups interact with coral reefs (the network hub) and with each other. Arrows represent the exchange of materials and information. This relationship diagram incorporates a range of methods in which coral biorepositories can be built including, cryopreserved samples, frozen (tissue) samples, live coral, and live symbionts.*

Process Flow Maps

Process flow maps are another important industrial engineering tool that can be used to analyze specific activities or processes that take place within the greater coral community. For example, in Figure 1, a relationship diagram was constructed to display the interactions of coral community members and highlight how biorepository samples move through the network. One key activity that could be evaluated further is cryopreservation. While different protocols for coral cryopreservation have been developed (Daly et al., 2018; Hagedorn et al., 2019), process maps can assist in increasing the reproducibility and scalability of these protocols. Process flow maps or diagrams are commonly used in industrial engineering to illustrate and understand all steps in a specific process (Renger et al., 2016). These diagrams display the sequence of steps used to produce a product and allow users to track how materials flow through the process (Damelio, 2011). Process maps are often applied in commercial-scale factory settings to help identify and eliminate wastes and bottlenecks, streamlining the process (Damelio, 2011; Manotas-Duque & Rivera-Cadavid, 2007). These diagrams have also been used in agriculture, with studies tracking the production cycle of farmed products (Apaiah & Hendrix, 2005). In the context of building a coral biorepository network, process flow diagrams can be used to standardize a protocol, increase protocol efficiency, and ensure the protocol meets the production demands of the greater coral community.

The first step in creating a process flow diagram is to identify and define all the steps of the process. Defining what tasks take place in each step, as well as the start and end points of each step, is imperative for keeping steps consistent throughout the study and for understanding the process as a whole. After the steps have been defined, they must be arranged in the sequence in which they occur. A helpful exercise when identifying, defining, and ordering steps is to perform the process yourself or observe someone performing it. This ensures no steps are left out, helps define boundaries between steps, and confirms that the sequence of steps is correct. After the sequence has been confirmed, the diagram can be created by visually representing each step in order using diagramming software, such as draw.io (JGraph, United Kingdom). Different shapes are commonly used to represent different parts of the protocol. In general, oval shapes indicate the start and end of the process, rectangles represent individual steps, rectangles with curved sides indicate a step where data are recorded, and diamonds represent decision points (Damelio, 2011). Arrows connect steps and show the flow of material and information through the process.

In Figure 2, a process flow diagram has been constructed that outlines the steps of a generalized coral cryopreservation protocol. After the diagram has been created, it can be evaluated to understand the overall process, distinguish between steps that “add value” to the end product and those that do not (waste), and plan improvements to the protocol (Damelio, 2011). Process flow diagrams can be used to generate quantitative data, as well when used in combination with another common industrial engineering tool, discrete-event simulation (DES) modeling.

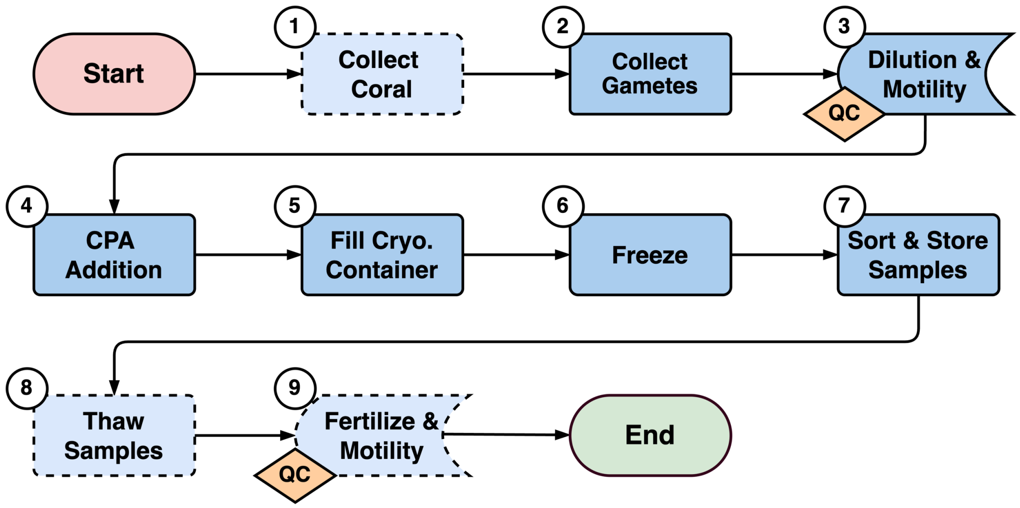

Figure 2. *A process flow diagram that outlines the steps, in sequence, of a generalized coral cryopreservation protocol. Shapes with solid lines indicate steps in the protocol that take place on the same day that samples are frozen. Shapes with dashed lines indicate steps in the protocol that can take place in the days before or after freezing. Rectangles indicate steps, and arrows indicate the flow of materials through the steps. Rectangles with two curved sides indicate steps were data is recorded, and diamonds indicate Quality Control (QC) steps.*

Simulation Modeling

Discrete-event simulation (DES) models emulate processes by modeling all the steps of a process throughout time (Allen et al., 2015; Gittins et al., 2020; Schriber et al., 2013). Logic rules can also be applied to make simulations accurately reflect "real world" processes (Schriber et al., 2013). A process flow diagram provides the basic structure for a DES model (Figure 3), and data collection through repeated time studies can be input into the model to simulate the amount of time required to complete the process. The resources that are used in the process (e.g., labor, equipment costs, supply costs) can also be inserted into the model (Allen et al., 2015). Through the use of DES models, the complexity of how protocols can meet the demands of the greater community can be captured. Informed decisions can then be made to improve protocols in a way that benefits community needs (Bodenstein et al., 2023; Gittins et al., 2020). For example, by evaluating coral cryopreservation protocols in the context of the surrounding coral community, decisions can be made about how what type of container coral samples should be frozen in based on logistical considerations like cost and ease of use. For additional information on how to construct and use DES models, please refer to the following publications: Bodenstein et al., 2022; Hu et al., 2015; Simio, 2016.

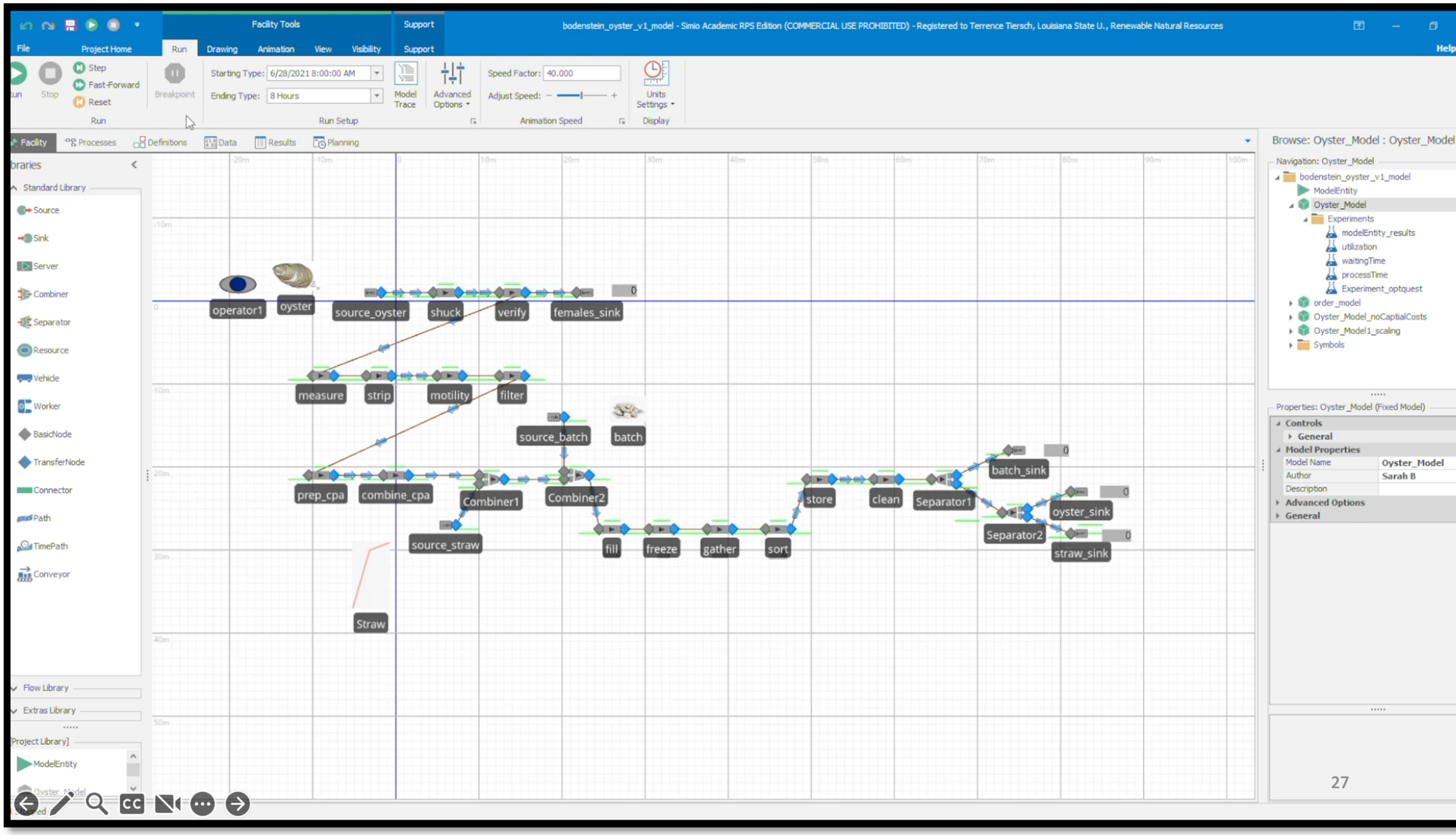

Figure 3. *A screen shot of the discrete-event simulation (DES) modeling software Simio (v14.230, Simio LLC, Sewickley, PA). The screen shot displays the structure of simulation model based on a process flow diagram for oyster cryopreservation. The model was used to identify bottlenecks in the system and propose solutions to increase efficiency (Bodenstein et al., 2022).*

Citations

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