Decoding Lagoon Dynamics

Visualization of the environmental forces that drive larval dispersal in the lagoon ecosystem surrounding Mangareva and Aukena Islands, in French Polynesia.

ABSTRACT

This project is an interactive simulation and interface prototype designed to approximate the larval dispersal of the black-lipped pearl oyster (*Pinctada margaritifera*) within the lagoon ecosystem surrounding Mangareva and Aukena Islands, in French Polynesia. The project aims to produce a conceptual decision-support visualization, exploring how complex spat collection and adult oyster restocking data can be made visually accessible to users. It was developed as an information design exploration for the course Art + Media Studio – Information Design at Aalto University; therefore, it operates as an academic interface prototype rather than a formalized scientific research project.

CONTEXT

Pearl farming is the multi-year aquaculture practice of cultivating marine oysters to produce pearls, relying on the natural lifecycle of the oyster. Oysters are a type of mollusk that lives in brackish and saltwater habitats that reproduce by spawning sperm and eggs into the water, which become larvae—known as spat (National Oceanic and Atmospheric Administration [NOAA], 2024). These larvae develop for 15 to 20 days before settling down, passing through phases of pelagic development—from free-swimming veligers to pediveligers—until they develop a specialized foot to seek a suitable substrate for attachment (Direction des Ressources Marines [DRM], 2022).

The farming cycle begins with 'spat collection'. Farmers place artificial lines of collectors into the water to catch free-floating oyster larvae just as they are ready to settle and attach to a surface (Bruyère et al., 2023). Once these juvenile oysters are collected, they are raised on underwater farms for long periods of time. After a few years of growth, a skilled technician surgically inserts a small nucleus into the oyster, which, over the next several years, the oyster coats with nacre—or mother-of-pearl—eventually forming a pearl (DRM, 2022).

In French Polynesia, this industry centers on the black-lipped pearl oyster, which produces the region's famous and highly valued black pearls (DRM, 2025). Pearl farming is the second largest source of income, right after tourism, of the region (DRM, 2025), it provides critical local employment and sustains the socioeconomic stability of these coastal communities (Cavallo et al., 2026). Within this territory, the Gambier Islands have historically been one of the most vital hubs for the industry, representing 25 % of French Polynesia's black pearl production in 2020 (Bruyère et al., 2023).

PROBLEM

For decades, the Rikitea sub-lagoon in Gam-

bier enjoyed highly stable natural spat collection, providing a steady supply of juvenile oysters. However, since 2018, this mechanism has collapsed into a severe 'recruitment crisis', with collection rates dropping to near zero between 2020 and 2023 (Bruyère et al., 2023). This decline is largely driven by climate change and wind instability, associated with La Niña cycles, along with rising sea surface temperatures that alter the lagoon's hydrodynamic conditions (ReefTEMPS Consortium, 2025; Bruyère et al., 2024). In practical terms, environmental changes physically prevent oyster larvae from remaining in their traditional harvesting areas long enough to be harvested, thereby affecting local pearl production. (Bruyère et al., 2023; Bruyère et al., 2024).

DATA & EMPIRICAL MODEL

Pearl farming research has gone through several exploratory phases; however, during a workshop in 2014, scientists and institutions realized that the main unsolved problem behind this crisis remained the highly unpredictable nature of natural larval collection (Andréfouët et al., 2022). To address this, the MANA Project (MANagement of Atolls, 2017-2022) focused on physical oceanography and three-dimensional numerical modeling (MARS3D) to study lagoon circulation (Bruyère et al., 2023).

This design project builds upon the dataset generated by a massive oceanographic campaign conducted in the Gambier Islands lagoon (specifically Mangareva and Rikitea) between 2019 and 2020. Specifically, it utilizes data from a network of _in situ_ sensors—ADCP_1, ADCP_2, ADCP_3, ADCP_4 (ADCP Sentinel V50), and Aqua1, Aqua2 (Aquadopp Nortek)—deployed during Leg 2 of the campaign (Bruyère et al., 2024). This dataset provides the foundational architecture of currents and temperatures for the period from late October 2019 to late February 2020.

SYSTEM DESIGN

The core contribution of this project lies in how these data and rules are visualized and manipulated by the user.

This project's development was divided into two main phases: data and simulation.
The first phase focused on data, which was collected from scientific papers and used to create a visualization of the lagoon surrounding Mangareva and Aukena Islands. The visual architecture of the map was constructed by extracting geographic coordinates from OpenStreetMap using Overpass Turbo, while the lagoon's topography was translated from high-resolution bathymetric data sourced from the SEANOE platform (Bruyère et al., 2025).

The second phase involves transitioning from geophysical mapping using existing data to creating a rule-based behavioral approximation model of larval movement in the lagoon. To achieve this, the simulation engine pre-calculates the entire larval lifecycle based on a set of biological and environmental rules. The model triggers oyster reproduction based on seasonal constraints (the austral summer months), real-time temperature fluctuations, with spawning probability increasing significantly when the water surpasses the 23.0°C threshold, and oyster population quantity and placements (Bionaz et al., 2022). Once spawned, the virtual larvae follow an age-dependent, 25 to 30-day lifecycle, where for the first 15 days of their pelagic phase, they exhibit diel vertical migration, actively moving to the bottom layer during the day and rising to the surface at night to ride different currents. After 15 days, entering the pediveliger stage, they permanently sink to the bottom layer to seek a settlement substrate. Throughout this lifecycle, the physical movement of the larvae is calculated using the interpolated vector fields from the oceanographic sensors, combined with a degree of randomized diffusion to simulate natural chaotic water turbulence. Additionally, the system includes geographic collision detection, meaning larvae bounce off landmasses (islands) but are removed from the simulation if they exit the lagoon boundary.

The interface translates the dataset into an interactive spatial-temporal simulation. The user observes a dynamic timeline that progresses through the historical environmental conditions of late 2019 and early 2020, visualizing the continuous flow of currents

and the density of larval dispersal, which are rendered on the map in real-time. The primary interaction allows users to place up to five artificial larval collectors within the lagoon. As the simulation runs, the system calculates the "Total Catch" for the specific coordinates chosen by the user. This provides immediate, legible visual feedback on the success or failure of a harvesting strategy, revealing exactly how micro-variations in temperature and current density affect localized areas.

RESULTS

The main outcome of this project is an interactive visual prototype that simulates a 4-month historical period (late October 2019 to late February 2020) by simulating the spatial trajectories of the larvae and actively calculating the catch rates per user-placed collector. It demonstrates to the user the fragility and unpredictability of larvae movements, showing why traditional, historically reliable collection areas can fail under shifting environmental forces.

DISCUSSION

Although the simulation is based on validated oceanographic data, it is crucial to recognize its nature as an exploration project rather than an operational tool for aquaculture. The project uses the inverse distance weighting (IDW) method for spatially interpolating currents; While this provides a credible two-dimensional approximation of water flow, it does not replace the depth and complexity of a comprehensive three-dimensional hydrodynamic model like MARS3D. Furthermore, the simulation is constrained to the specific timeframe of the Leg 2 campaign, meaning it cannot currently predict future events or other anomalies in the climate cycle. And the larvae simulation is approximate rather than based on fully reliable and real data.

However, the primary objective of this project was not to provide a flawless scientific instrument, but to serve as a possible first step toward the information visualization and interface design of a future decision-support tool, exploring how complex data on spat collection and oyster restocking can be made visually accessible to users. Therefore, it achieved its intended goal, although it would have benefited from discussions with field experts and user testing, which were impossible to perform in the short time this project was developed.

CONCLUSION

In conclusion, this project illustrates how data visualization and interaction design can be leveraged to communicate complex socio-ecological challenges. By simulating larval dispersal in the lagoon surrounding Mangareva and Aukena Islands, the prototype transforms abstract scientific measurements into an interactive visualization of climate vulnerability and environmental instability. Although developed as a conceptual design exploration rather than a formal research project, it effectively demonstrates how decision support systems could be structured to foster better understanding. Ultimately, making environmental data visually accessible and interactive is a critical step in helping stakeholders and coastal communities understand the changing dynamics of their ecosystems, potentially helping them adapt their aquaculture strategies to an increasingly unpredictable climate.

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