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Hacking Bioluminescence: A living laboratory in Puerto Mosquito

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Thesis prep & Thesis book
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I. Introduction

II. The magic of a bioluminescent bay
   puerto mosquito bio bay

III. Creatures of light: the production of bioluminescence

IV. The Living Laboratory
Design and Biology create a re-engineered ecosystem for human inhabitation in the periphery of the bioluminescent bay. The integration of two innately distinct disciplines provides a living area for people and also serves as an educational tool that will put them in close contact with the bio-chemical process of bioluminescence.

**Site:** Puerto Mosquito Bioluminescent bay
  Vieques, PR

**Proposal:** Living laboratory

**Program:** living units
  communal space
  observatory
Following a study of the chemistry and biology behind the process of bioluminescence and an understanding of the components of a bioluminescent bay, the project proposes a living laboratory in the Puerto Mosquito bioluminescent bay for the appreciation of bioluminescence.

To prevent detrimental effects upon the ecology resulting from the anthropogenic presence, a feedback system that redirects waste and resources among the programmatic components is implemented. The waste from one activity will be recycled to become the input for another.

“There are places in the world where diving into the water on a moonless night is like diving into a sea of sparkling stars.”1

Puerto Mosquito bioluminescent bay, located on the southern shore of Vieques Island, was officially declared the brightest recorded in the world by the Guinness Book of World Records in 2008.2 This bay has the perfect environmental conditions for the bioluminescent dwellers. The Bay is small and shallow and has a narrow entrance, so the bright tiny organisms stay trapped, making it very bright. Bioluminescent bays attract thousands of tourists from all over the world eager to see and swim in the water full of sparkling microorganisms, an experience that will surely be unforgettable and will leave anyone amazed. Excessive tourism influx, however, can be detrimental to the well functioning of the bay. With the tourism demand comes an overdevelopment of nearby areas as well as the use of motorized watercraft in order to provide the necessary and wished amenities for foreign tourists and local visitors wanting to access the bay. Factors such as upland water runoff, garbage and oil spilling from boats affect negatively the quality of the water and therefore the bioluminescent microorganisms. One of the three bioluminescent bays in Puerto Rico, in the town of Lajas, has lost almost all of its bioluminescence capacity due to the consequences of excessive tourism. In order to avoid the extinction of this natural wonder while allowing anthropogenic presence, tourism has to be properly managed. Architecture as a physical intervention can become the interface between the two.

“Many organisms, from fireflies to bacteria, exhibit the fascinating trait of bioluminescence. It is relatively rare among land dwellers, but in the depths of the ocean more than 90% of animal species are capable of generating light”.2

Bioluminescence is the production and emission of light by living creatures. When the proper combination of geological and climatic factors are present, during the night it is possible to witness one of the most fascinating natural phenomena when millions of these organisms leave a trial of neon blue after been disturbed.

The magic of a bioluminescent bay
"Bioluminescent bays are uncommon due to its delicate nature and surrounding ecological issues. The phenomenon of luminescence occurs irregularly in tropical waters around the world."¹

The water luminescence is triggered by dinoflagellates, an oceanic plankton which is able to generate an emerald green and ultramarine illumination when water is physically disturbed. Environment conditions such as balance of salt in the water, local climate, deepness of lagoon, air and water pollution contribute to the occurrence of bioluminescence. Each one of these aspects make the bio bay a one of a kind, vulnerable ecosystem.

Bioluminescence occurs after light has been collected in the daytime. As a result, the best possible view of bio-luminescence comes after a sunny day. The ideal time frame to encounter the luminous bio bay water phenomenon, also referred to as phosphorescence of the sea, is at night. The intense neon illumination happens to be more noticeable with least light pollution.

¹ HTTP://BIOBAYPUERTORICO.COM/LA-PARGUERA-BIOLUMINESCENT-BAY/
Ecosystems of the bay

[Map of Puerto Mosquito with various生态系统的标识和深度标注]
Environmental conditions

Factors influencing concentration of dinoflagellates:

- **Wind**: causes water column mix, resuspending sediments and moving dinoflagellates.
- **Tide**: low tides keep high concentration.
- **Rainfall**: no freshwater tolerance.
- **Sunlight**: photosynthetic organisms.
- **Nutrients**: from mangrove (vitamin B12).
- **Temperature**: lowest 5°C, highest 37°C - no heat tolerance.
The sedimentology of the bays affect the life of the bioluminescent organisms. Sediments in Puerto Mosquito, for example, are coarser and therefore of easier deposition than in La Parguera. When sediments stay suspended, light infiltration during the day becomes difficult and photosynthesis cannot happen properly. Higher sediment suspension could be due to the tourism exploitation of the place (e.g. constant boat traffic recirculating the water).

**Sedimentation**

**TERRIGENOUS SEDIMENTS**

**FROM UPLAND EROSION**

LIGHTER SEDIMENTS: STAY SUSPENDED

**CARBONATE SEDIMENTS**

**CALCAREOUS DEPOSITS**

COARSER SEDIMENTS: MORE CONCENTRATION OF ORGANISMS DUE TO LIGHT INFILTRATION

![Terrigenous Sediments](image1)

![Carbonate Sediments](image2)
Mangroves play an important ecological role. They are transition ecosystems between terrestrial and marine environments, acting as buffers to protect the land from waves and strong winds. Thriving in bodies of water with high salinity, they provide shelter and feeding areas for marine life including phytoplankton, fish and crustaceans. The root system, with bacteria and algae attached, stabilizes and traps sediments washed off the land, transforming inorganic material into organic (e.g. acids). The red mangrove, the closest to the bay and the most water tolerant, provides vitamin B12 for the bioluminescent dinoflagellates. Mangroves are also carbon sequesters, playing an important role in climate change mitigation.
Bay salinity: 35-37

Ocean salinity: pH 35 ppt

Warmer water from the sea enters the bay and stays on the top layer until it gets colder and sinks, eventually leaving the bay from the bottom layer.

33-37 ppt functioning salinity range

35 ppt - average ocean salinity

Dinoflagellates have no freshwater tolerance. After a rain event recruitment happens (bioluminescence stops). In 3-4 days bioluminescence goes back to normal.
CREATURES OF LIGHT: THE PRODUCTION OF BIOLUMINESCENCE
Bioluminescence: a chemical reaction that burns fuel and releases light with such perfect efficiency that it barely produces heat.¹

90% light
10% heat

Energy shot out almost entirely as photons of light
More suitable for tracing, warning, ambience and indication than functional illumination

Incandescence: emission by a hot body of radiation that makes it visible

10% light
90% heat

Fig. 1

Fig. 2

¹ Bioluminescence: lights for living, living for lights.
LUCIFERIN + LUCIFERASE + OXYGEN = LIGHT

Range of most bioluminescent organisms
Best visual appreciation at night

400nm 700nm

FORCE 0.1 sec
“Since the majority of the ocean’s volume lies below the reach of the sun’s rays, enveloped in perceptual darkness, marine creatures that can produce their own personal flashlights possess an advantage.”¹ Some of the living creatures that produce luminescence include bacteria, protozoa, fungus.

The reasons for the production of light include distraction, avoid predation, counter illumination, and the burglar alarm theory. It is the only biological process that provides its own visible indicator of the rate at which it is taking place (the intensity of emitted light).

The most prominent bioluminescent organisms in the ocean are single-celled animals called dinoflagellates (fig. 1). Along with other glowing marine organisms, dinoflagellates transform the dark ocean into a bioluminescent minefield. The largest, Noctiluca scintillans (fig 2), measuring up to a millimeter in length is the most abundant.²

Dinoflagellates are one of the most important members of the phytoplankton community(fig. 3) in our marine and freshwater ecosystems. They are at the bottom of food chains and carry out the initial transfer of light energy to chemical energy in aquatic ecosystems. All other organisms are dependent upon this energy transfer for their subsequent existence.³

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**Phytoplankton** — **Dinoflagellates**

**Plankton** — **Zooplankton**

**Bacterioplankton**

**Nekton** — **Fish, Octopi, Whales**

**Benthos** — **Bottom dwellers**

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¹ Gruber. A Glow in the dark. p4
² Spector. Dinoflagellates. p1
³ Gruber. A Glow in the dark. p8

[Fig 1 & 2: http://beybieluhb20.blogspot.com/2012/02/noctiluca-scintillans-sea-sparklesea.html](http://beybieluhb20.blogspot.com/2012/02/noctiluca-scintillans-sea-sparklesea.html)

1. Swimming microorganisms
2. Single dinoflagellate
3. Thecal plate (armour) with vacuole inside
4. Vacuole
5. Scintillion (where the chemical process occurs)
6. Luciferin (substrate) and luciferase (catalyst) are produced internally by the organism
7. After action potential, ion channels open to allow for change in pH from 8 to 6
8. Oxygen particles enter
9. Luciferin and luciferase combine
10. Luciferin + luciferase + oxygen
11. The union produces the light
12. Hundreds of scintillion in one cell emitting photons of light

Action potential sequence of pictures: "how bioluminescence works" http://www.youtube.com/watch?v=IE5v1ZqHME
A wide diversity of cortical vesicle shape and size is found among the dinoflagellates. These vesicles are arranged into interesting patterns such as random mosaics, brick wall, or honeycomb.
Cell motility

Central axis of rotation
Move freely, sometimes swimming in groups of 2, 3, 4.

Distance (inch) | Time (sec)
---|---
0.25 | 0.5
0.5  | 15

Points

Rotation between points

Move freely, sometimes swimming in groups of 2, 3, 4.
Bioluminescent dinoflagellate

**Circadian Clock: Replenishable Resource**

**Photoautotroph Organism:** In alternating period of 12hrs, luminescence is greater during dark period.

**Ideal Temperature Range:** 5\(^\circ\) - 37\(^\circ\)
- Resistant to cold but not to heat

**Natural Cycle**

- L = light
- D = dark
- Circles = 1 lit.

**Mechanical Stimulation**
- **Full Luminescence**
- **No Visible Luminescence**
- **Dead Organisms**

- 25\(^\circ\)C
- 20\(^\circ\)C
- 37\(^\circ\)C
- 5\(^\circ\)C

- 10,000+ foot candles
EXPERIMENT 1

L = 300 - 600 FOOT CANDLES

*ALL CIRCLES = 1 LIT
rising temp.
Vibrio fischeri is a rod shaped bacterium commonly found in marine environments. It has bioluminescent properties and works typically in symbiosis with various animals such as the squid. The bioluminescence is caused by transcription induced by quorum sensing, luminescence only seen when population reaches a certain level. Similar to the dinoflagellates, they follow a circadian rhythm, glowing brighter during nighttime.¹

¹http://www.nottingham.ac.uk/quorum/fischeri.htm

**Fig. 1** http://microbewiki.kenyon.edu/index.php/Vibrio_fischeri

**Fig. 2** http://aem.asm.org/content/75/1/193/F6.expansion.html
Quorum sensing: bacterial language

Light emitted: 490

Efficiency: 98% emitted as light and

Even slight toxins we can’t smell can alter the bacteria’s metabolism and will reduce the amount of light they produce (pollution detectant). Clean water doesn’t affect the metabolism or how bright it glows.

(Nutrient agar)

(Marine water)

http://www.nottingham.ac.uk/quorum/fischeri.htm
http://serc.carleton.edu/microbelife/topics/marinesymbiosis/squid-vibrio/index.html
The Living laboratory
EDUCATION
RECREATION
EXPERIENCE
RESEARCH
IN INVOLVEMENT
REAL ENVIRONMENT

LIVING LABORATORY
Daily living and working routine: eliminating the footprint of human inhabitation

Waste to resource

- **Greywater**: Used for flushing toilets, irrigation, and other non-potable uses.
- **Trash**: Collected for disposal, possibly composting or recycling.
- **Blackwater**: Sediment and effluent from sewage systems, treated for nutrient recovery.
- **Urine**: Collected for nutrient-rich biofertilizer, possibly used in composting toilets.
- **Food Scrap**: Converted to biogas and compost for garden use.
- **Liquid Disposals**: Catalytic converter, filtration systems for waste management.

**Calculating the Retention Time:**

- **3 hrs x 40 days = 120 lbs / 8.3 = 14 gal/day = 2 ft³ per person**
- **2 ft³ x 16 people = 32 ft³**

**Gas Production:**

- **0.5 lbs of food for consumption**
- **2.2 lbs = 0.4 m³ of gas**
- **= 1 hr of cooking**

**Feedstock:**

- **1000 lbs of feedstock = 300 kw/h (300,000 w/h)**
- **30-60L per person to prepare 1 meal**
Cycles of recycling

1. septic tanks → bacterial lines → human use
   - black water

2. food waste + vegetation → biodigester → gas → fertilizer → plants
   - cooking electricity

3. greywater flow → living machines
   - shower faucet
   - laundry dishwasher

Alternative sources:
- solar energy
- water harvesting
- collector
- computers
- septic tank filtration system
- inlet faucets shower extra
- tank
- filtration
VIEW OF A LIVING POD
plumbing tree

feeding the bacteria

60 °

30 °

filtration system

pump

effluent from toilet
bacterial lines: re-engineering biology

inner tube containing effluent: 1” OD   aluminum

outer tube containing bacteria: 3” OD   acrylic

modular pipes

10’ long

outside temperature: 80o F
Microbial community plan

scale: 1/8 = 1"

A food waste to gas cycle
B bacterial cycle
C greywater cycle

Beach

Bio Bay
STRUCTURE OF THE POD: BAMBOO SKELETON

Living pod

Communal pod

MAIN STRUCTURE  3” POLE THICKNESS  MEDIUM STRUCTURE  2” POLE THICKNESS  DETAILS  1” POLE THICKNESS

MAIN STRUCTURE  3” POLE THICKNESS  MEDIUM STRUCTURE  2” POLE THICKNESS
floor supports
3" and 2" bamboo poles

BAMBOO JOINT CONFIGURATIONS

MESH

ENCLOSURE

FLOOR SUPPORTS
3" and 2" bamboo poles

BAMBOO JOINT CONFIGURATIONS

A1

A2

A3
VIEW FROM THE OBSERVATORY
VIEW FROM THE LIVING POD
VIEW TOWARDS THE COMMUNAL SPACE
VIEW TOWARDS THE COMMUNAL SPACE AND OBSERVATORY