Environmental Assessment Framework for Floating Development

French Polynesia

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Preface

Blue Frontiers (BF) believes that experiments are the source of all progress: to find something better, you have to try something new. However, experimenting with new technologies and new societies requires open space, but land is in increasingly limited supply. To tackle this situation, BF advocates seasteading communities — floating developments creating space on water —allowing the next generation of pioneers to test ideas about how to live together sustainably and harmoniously.

In fall 2016, the non-profit think tank, The Seasteading Institute (TSI), was invited to French Polynesia to examine if French Polynesian waters are suitable for seasteading. Soon afterwards, a spin-off company was founded from this initiative, that is Blue Frontiers (BF). BF committed to do 'no environmental harm' instead of conducting a standard Environmental Impact Assessment (EIA). BF aspired to go much further: to improve on the current environmental status. The goal is to set the environmental standard for prospective floating infrastructure in an "Environmental Assessment Handbook." Before producing this handbook, however, we present a new framework for environmental considerations related to floating infrastructure in natural environments.

The framework presented in this report emphasizes the environmental integration of floating infrastructure in a predefined area of water (also known as a "SeaZone"). The objective is to provide relevant information supporting good decision-making by stakeholders at all levels, and go beyond standard EIA. The report also provides inputs for developing a checklist of environmental standards for future floating developments.

Development of the Handbook

The "Environmental Assessment Handbook" will be a step-by-step guide for floating infrastructure within a SeaZone, with recommendations for infrastructure characteristics that aim to keep key ecosystem parameters (indicators) within benchmarks reflecting good environmental status. The handbook will be adapted to different environments and locations around the world. The initial version focuses on the tropical coral reef environments of French Polynesia. The handbook is intended to be a dynamic document that evolves according to research findings obtained during the lifecycle of the floating infrastructure. Such dynamic feedback requires inputs from a range of stakeholders, especially the scientific community. As a model, a long-term collaboration with local researchers in French Polynesia is being established under the Polynesia Floating Infrastructure Research: Science and Technology (FIRST) Consortium.

1. Introduction

French Polynesia is considering giving Blue Frontiers (BF) the unprecedented opportunity to realize their first floating community. This will be the first step in pioneering floating communities to instigate social, technical and design innovations. The intention of BF is to help create floating communities that are connected to and co-evolve with the location that is hosting them.

In order to make the best decisions for both of the environment and humans, a new framework on how to assess human impact on the environment is proposed in this report. The methodology for assessing the environment will be more elaborate than present environmental impact assessments, which focus more on a one-time procedure. The new methodology consists of using a feedback loop approach (also referred to as network approach) and using monitoring of the predicted effects in order to maintain preset benchmarks. Such methodology could equally be applied on land, though our focus here is floating infrastructure in the SeaZones.

Instead of carrying out an independent environmental impact assessment for each floating platform within a SeaZone, we propose that the SeaZone as a whole should be compared with one, and preferably more pre-defined control zones during a long period of time, hereinafter referred to as Environmental Control Area. This Environmental Control Area regulatory model uses the Before After Controlled Impact Pairs Series (BACIPS) approach developed at the French Polynesia's own Gump Station (Thiault et al., 2017; Osenberg et al., 2011). For the SeaZone and each control zone, the current environmental state and future trends of physical, chemical and biological parameters will be estimated/predicted and the habitat types will be identified. The analysis of environmental parameters and the identification of habitat types will allow an estimation of the SeaZone's ecosystem vulnerability to potential hazards posed by floating infrastructure. At the same time, the analysis will help shed light on environmental challenges (e.g., degradation due to pollution) in the SeaZone, for which the floating infrastructure might offer solutions.

The framework is based on the monitoring of environmental parameters that are pre-set for measuring the ecological health of a SeaZone. As long as the parameters stay within the benchmarks – designed to minimize negative impacts and maximize benefits for the environment – floating developments within the SeaZone can be extended, according to the guidelines.

These benchmarks and guidelines will be codified in the package of legislation that allows for the creation of SeaZones. The administrators of the SeaZones will be responsible for abiding by the framework, as stipulated in the "Environmental Assessment Handbook" agreed for their SeaZone. This will facilitate the expansion of floating developments while keeping the highest standards for environmental protection.

1.1. Scope and structure of the report

Following this introduction, Chapter 2 describes the environmental challenges of French Polynesia along with the main elements of the country's environmental policy. In Chapter 3, the need for developing a new framework and the resulting benefits for French Polynesia are described, following with the introduction of the framework itself. Additionally, Chapter 3 overviews several key environmental parameters from three facets (physical, chemical and biological) that need to be addressed when preparing for the development of a SeaZone. Chapter 4 to 12 elaborates the different parameters of the marine environment and how they can be positively or negatively influenced by the presence of human activities in general, and specifically floating infrastructure. Each chapter provides points of attention, summarizing potential ecosystem vulnerability and impact assessment to the introduction of floating infrastructure. Design and mooring recommendations are given when applicable. In Chapter 13, general remarks and conclusions are presented and potential opportunities are highlighted. The Environmental Code (Code de l'environnement de la Polynésie française) is shown in Appendix 1. In Appendix 2 and 3, the abbreviations and terminology used in this report can be found.

It is important to note that this report focuses on the "assessment" of the effects of floating infrastructure and related human activities on the "environment." Other considerations, such as socioeconomic effects on stakeholders or engineering challenges associated with floating infrastructure, are also of vital importance but fall outside the scope of this report.

2. Background information

2.1. Environmental challenges in French Polynesia

With 118 islands and atolls scattered over a vast area about the size of Western Europe in the South Pacific Ocean, French Polynesia is culturally unique and ecologically rich (Page, 2014). The country has among the highest density of coral reef formations and atolls in the world and is a biodiversity hotspot that shelters abundant marine and terrestrial biodiversity. French Polynesia's private-sector economy is dominated by tourism, which depends on the country's extraordinary natural and cultural heritage. Fisheries, aquaculture (for food and jewelry – Tahitian cultured pearls), as well as agriculture are key elements of Polynesian society and culture, contributing to food security, public health, and social well-being.

With its geographic isolation and human society still tightly connected to nature, French Polynesia is economically and environmentally vulnerable to globalization and humanity's increasing pressure on planetary life support systems. In the Environmental Vulnerability Index developed by the South Pacific Applied Geoscience Commission and the United Nations Environment Program (South Pacific Applied Geoscience Commission, 2015), French Polynesia is ranked 'extremely vulnerable' due to various challenges leading to ecosystem imbalance, landslides and species extinctions.

The challenges French Polynesia faces are a microcosm of those facing the planet. They are multifaceted and interconnected. For example, coral reefs are particularly sensitive to the likely impacts of rising atmospheric concentrations of carbon dioxide: global warming (elevated sea temperatures are one of the main causes of coral bleaching[1]), changing precipitation patterns and intensification of storms, rising sea levels, and ocean acidification[2]. Environmental change also threatens terrestrial biodiversity, as insular species have limited opportunity to migrate to areas with more favorable conditions, while invasive species are a byproduct of increased travel and trade associated with globalization. With limited land area, terrestrial biodiversity is also threatened by changing land use associated with population growth and urbanization.

Furthermore, these threats often act in concert. For example, untreated wastewater flowing into lagoons, which can be exacerbated in areas with high local and/or tourist population densities, might result in further degradation of habitats already stressed by global warming (de Bettencourt and Imminga-Berends, 2015). To support the health of ecosystems and thriving human populations, it is crucial that stakeholders of future developments in French Polynesia, including floating infrastructure, take into account

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[1] Loss of coral pigmentation through the loss of intracellular symbiotic algae (known as zooxanthellae) and/or loss of their pigments (IPCC, 2014).

[2] A reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean (IPCC, 2011).

global change and employ locally-adapted measures to promote sustainable development.

2.2. Environmental policy: relation to floating infrastructure

Floating infrastructure is a relatively new phenomenon worldwide and requires specific environmental approaches not fully covered in existing regulatory frameworks. Furthermore, environmental regulations in general are maladapted in an era (the Anthropocene) when human impacts on the planet can no longer be ignored. A radical paradigm shift is required away from merely minimizing ecological damage to a more regenerative vision where human development aims to strengthen ecosystem resilience. As the environmental regulatory regime for floating infrastructure remains to be written, we have an opportunity – and indeed a responsibility – to shape it under this new paradigm of "regenerative" development.

As the first country to legislate for a SeaZone, French Polynesia has an opportunity to influence emerging environmental frameworks for floating infrastructure globally. While developing general principles with universal application, we must also identify considerations that are specific to the regional (Pacific Islands) and local (French Polynesia) context.

Environmental impact assessment and strategic environmental assessment in Pacific island countries

In 2016, the Secretariat of the Pacific Regional Environment Programme (SPREP) published guidelines to strengthen environmental impact assessments in Pacific island countries and territories (2016). Two environmental assessment processes were defined that are applicable at different scales:

- **Environmental Impact Assessment (EIA)**, *project scale* – a two-way process for identifying and managing: (1) a development's potential impacts on the environment, and (2) the potential impacts of the environment on a development. Examples of development projects that may be subject to EIA include a new wharf, tourist resort, airport upgrade, renewable energy project, fish cannery, mining or logging operation.
- **Strategic Environmental Assessment (SEA)**, *policy, plan or program scale* – a higher-level process that can be used in three main ways: (1) to prepare a strategic development or resource use plan for a defined land and/or ocean area; (2) to examine the potential environmental impacts that may arise from, or impact upon, the implementation of government policies, plans and programs; and (3) to assess different classes or types of development projects, so as to produce general environmental management policies or design guidelines for the development classes/types. All three types of SEA aim to create a context for sustainable and resilient development and to avoid or minimize cumulative impacts.

The current document – our Environmental Assessment Framework for SeaZones – clearly falls under the second category. A specific EIA will follow when the location of a proposed SeaZone is known along with details of the specific projects proposed for that SeaZone.

Environmental Impact Assessment legislation in French Polynesia

The Environmental Code (Code de l'environnement de la Polynésie française) was adopted 15 December 2003 and replaced part of the Development Code (Code de l'aménagement de la Polynésie française). It has been revised and amended several times over the past decade. The content of the EIA is shown in Appendix 1.

Current Environmental Protection Policy and Reforms

In 2016, president Édouard Fritch announced the plans for Tainui Atea, a 5 million km² Marine Managed Area (MMA)(Cluster Maritime de Polynésie française, 2016), comprising most of the Exclusive Economic Zone of French Polynesia. Depending on the eventual terms of management, it could be by far the largest marine "protected" area in the world (note: the word "protected" has various interpretations, but can be synonymous with "managed" when the management strategy prioritizes ecological resilience). The initiative further fortifies the Declaration on the Ocean (Te Moana O te Hiva) signed by the Polynesian Leaders Group in June 2016, referring to Ocean Day at COP21 (Polynesian Leaders Group, 2016).

Following implementation of the Marine Management Plan (PGEM) for the island of Moorea, protected or managed marine areas in French Polynesia have increased by more than 50% since 2006, for example, with the establishment of the Fakarava Biosphere Reserve and new regulated fishing zones in Mahina, Tetiaroa and Punaauia (Direction des ressources marines et minières, 2017) and a protected area of natural resource management on the Tahiti peninsula (Creocean, 2015).

Regional initiatives to create a fully protected marine reserve around the Austral Islands and Marquesas Archipelago have stalled for various reasons, including the perception (real or otherwise) that they might restrain local people that depend on fisheries. Managing marine resources is part of Polynesian culture and there is great opportunity to combine traditional knowledge with scientific understanding. These opportunities offer the best hope to enable the sustainable coexistence of different uses of Polynesia's vast maritime patrimony, such as for fishing, tourism, energy, aquaculture, commerce, and research (The Tahiti Traveler, 2015; Valentine, 2016).

Environmentally regulated zones

There are several specific environmentally regulated zones in place:

- **Moorea**: Direction de l'Environnement (DIREN) "Plan de Gestion de l'Espace Maritime (PGEM) de Moorea", October 2004, implemented after seven years of maturation, aimed at sustainably managing the diverse uses taking place in the lagoon and offering ecosystem protection. Since 2008, Moorea's lagoon was classified as wetland of worldwide interest under the international Ramsar Convention.

- **Fakarava**: UNESCO Man and Biosphere (MAB) reserve, involving seven atolls within the municipality.
- **Marquesas**: PUKATAI network of Educational Managed Marine Areas (EMMAs) in the six inhabited islands of the Marquesas archipelago.[3]
- **Regulated fishing zones (ZPRs)** and traditional "rāhui" are applied in various locations around French Polynesia.[4]
- French Polynesia is the center of some of the most advanced monitoring of coral reefs in the world. Notably the long term scientific studies on Moorea (through the international marine labs: CNRS-EPHE-UPVD CRIOBE and Univ. California GUMP) and the broader coral reef monitoring programs coordinated around French Polynesia and the South Pacific by the CRIOBE.

Biodiversity regulations and Species protection

The protection of local species is regulated in the Environmental Code and the responsible authority is the Council of Ministers in French Polynesia. Efforts to protect species have more than doubled in the past decade, but the focus is on prevention of collection and the exportation of species. The list of protected species has recently been modified and updated. They could be found in Category A & B.

Category A includes:

- 167 protected plants
- all terrestrial snails belonging to the family of the Partulidae
- 38 bird species (12 new species compared to 2006)
- 4 species of marine turtles
- 4 species of shellfish
- a stingray species

Category B includes marine animals, such as the green turtle, sharks, whales and dolphins, and sandalwood. (Note: specific terrestrial and marine flora and fauna at the selected project site within the SeaZone could be identified after conducting detailed surveys).

French Polynesia is the first community to protect sharks. Moreover, a marine sanctuary was established throughout its Exclusive Economic Zone. New species cannot be introduced without approval from the French Polynesia government.

In addition, international treaties apply, most notably the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), regulating cross-borders exportation of species. At the international scale, the Management authority is the "Haut-Commissariat de Polynésie française."

[3] Which was setup by one of the ambassadors of The Seasteading Institute, Pascal Erhel.

[4] Rāhui is a temporary no-take area, established by the local community.

3. Environmental assessment framework

3.1. Philosophy and goals

The philosophy for SeaZones advocated by Blue Frontiers is as follows:

“The areas that become administered by a SeaZone authority should be cared for so that its environmental status is at least as good as those from comparable control areas, and preferably in a way that increases the resilience of ecosystems."

To meet this goal, environmental stewardship should not be a traditional one-time impact assessment but a process of adaptive management. In the Environmental Control Area (ECA) model, ecological benchmarks (boundaries) provide the framework (targets) for floating infrastructure or other aspects of the built environment. Dynamic (even real-time) monitoring of the on-going interaction with the environment (indicators) determines whether agreed ecological boundaries (targets) are respected. The philosophy underpinning this approach recognizes the need to gradually learn what works and what does not, improving and adjusting technologies and behaviors accordingly. Top-down regulatory model try to freeze nature in place. The ECA model offers a more flexible and scientific approach.

The SeaZone will do more than just set a good example for sustainable development, however. It will also likely generate innovations suitable for adoption more broadly, both locally and globally. Some of the intended benefits for by island and coastal communities, and the planet as a whole, are listed below.

Potential benefits (local, national, global) of SeaZones and Floating infrastructure

- Floating infrastructure might be an important long-term solution for coastal communities adapting to sea level rise.
- Floating infrastructure might offer opportunities for climate change mitigation and adaptation. For example, floating solar farms or algae farms taking up CO_2
- Floating infrastructure offers more flexibility than projects on land, as the location of the development is more easily changed even after its implementation.
- Integration of new technologies in the SeaZone, such as energy generation, waste reduction, and wastewater treatment, is essential for floating infrastructure to have a regenerative impact on the SeaZone environment, and these advances could also be valuable for other coastal areas.
- The influence of the first floating development on its surrounding environment will be regularly monitored using technologies such as remotely operated underwater vehicles, drones, sensors, and other data collection devices. The data will be made available as appropriate in an open-source manner as determined in collaboration with the FIRST Consortium. This means that the first floating development can contribute to educational purposes locally and internationally, and can be evaluated transparently in close collaboration with local and international scientists and environmental experts.

3.2. Framework

The framework for the environmental assessment of floating infrastructure has been inspired by the document on strengthening the environmental impact assessment methodology (EIA), as described by the Secretariat of the Pacific Regional Environment Programme (SPREP, 2016).

The procedure to create a SeaZone with her own environmental impact assessment authority will consist of the following steps:

- Defining the responsibilities clearly for who administers the SeaZone and who carries out (scientific) monitoring of environmental status and procedures to avoid real or perceived conflict of interest and to ensure appropriate access to data and models used to assess environmental status (e.g., IDEA Consortium social technologies coupled to computational data science infrastructure)
- Defining the SeaZone, where the floating developments will take place
- Defining one or (preferably) more control zone[5]
- Starting with a base-line analysis of the existing ecosystem for both the SeaZone and the control zone(s) BEFORE any intervention in the SeaZone
- Quantifying (through scientific models and simulations) the expected influence of floating infrastructure on the ecology of the SeaZone under various scenarios, including those under the control of the SeaZone authority (e.g., waste management protocols on the platforms) and those outside of its direct control (e.g., climate change and ocean acidification).
- Setting benchmarks as targets for the simulations to assess, with appropriate measures of uncertainty, if the floating infrastructure is likely to maintain the ecosystem within those safe boundaries
- Setting up a plan for monitoring and measuring the effects in order to assess if goals are being met and to refine and improve SeaZone authority policy to maximize the likelihood of maintainin the environment within the predetermined benchmark boundaries
- Using the analysis (BACIPS framework) of global and local trends affecting the SeaZone and control zone(s) in order to identify the likely causes of any deviation from the predefined benchmarks

[5] More control sites provide more statistical credibiility and scientific rigor.

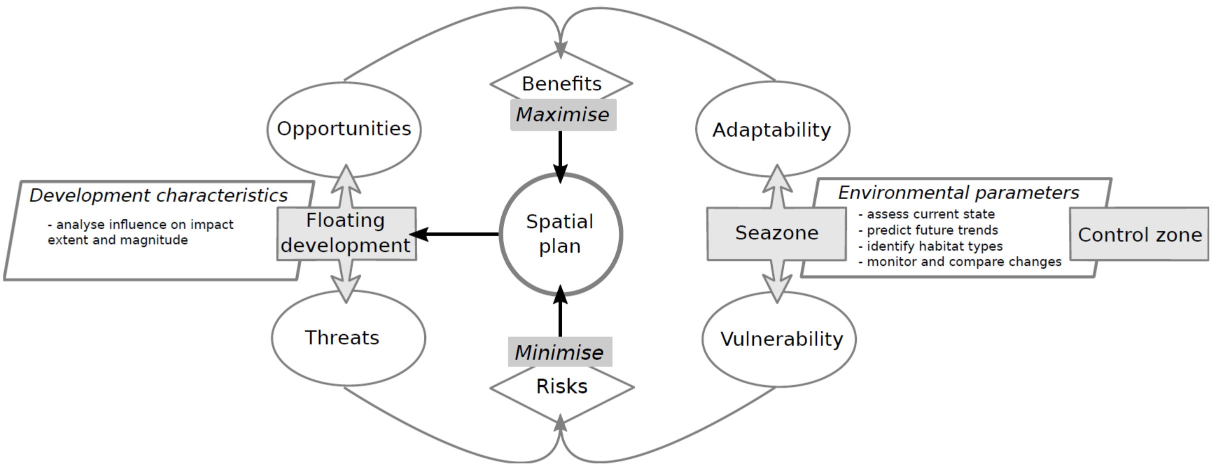

Figure 3.1: An overview of the proposed framework

Figure 3.1 presents the scheme of the proposed framework. In the SeaZone (right part), the ecological characteristics of the SeaZone are analyzed. Important parameters that help evaluate ecosystem health are measured and compared to suitable control sites where floating infrastructure will not be deployed in the near future (note: the selection of a "control zone" is a complex scientific issue, which could include multiple sites, and is simplified here for illustrative purposes).

Parallel to the assessment of the ecological characteristics of the SeaZone, the characteristics of the built environment (floating infrastructure) are analyzed (left part) including environmental threats to the infrastructure and benefits that the infrastructure could provide for the environment (opportunities).

The interaction of the vulnerability and adaptability of the SeaZone with the threats and opportunities of the floating infrastructure lead to a spatial plan for the SeaZone, describing what is possible (in terms of density, use and functions) and where different types of floating infrastructure might be located within the SeaZone. This process also feeds back to make recommendations for the engineering decisions and technologies used (specifications for the floating structures). There is therefore an iterative approach to developing the initial spatial plan and for its subsequent evolution.

Predefined environmental parameters (indicators) of the SeaZone and control zone(s) will be continuously monitored by credible and independent agencies (e.g., the FIRST consortium) making their data and interpretations available for public scrutiny (e.g., publishing findings following best practice in open science). The information gained in this way will be used to validate pre-construction simulations, and as necessary, to reassess the models of how the floating infrastructure interacts with the environment. As knowledge grows based on real-world experience, the spatial plan of the SeaZone should be adapted accordingly, modifying existing infrastructure as needed and incorporating improvements in any new floating infrastructure planned for the SeaZone.

Additionally, based on the current state and future development of environmental parameters, benchmarks (boundaries) will be set for each parameter. More floating infrastructure can be added to the SeaZone so long as the monitoring shows that benchmarks are being met, and that scientific simulations indicate reasonable confidence that any additional infrastructure will maintain or improve overall environmental status.

Monitoring a control zone through the Before After Controlled Impact Pairs Series (BACIPS) approach (Thiault et al., 2017) allows distinguishing ecological changes in environmental parameters (indicators) that are likely to have happened in the absence of the floating infrastructure.

As stated earlier, SeaZones are intended to strengthen ecological resilience and increase ecosystems services derived by the human population. Demonstrating that floating infrastructure can have such a net benefit (win-win) for nature and for society requires assessing *what would have happened in the absence of the floating infrastructure*. Clearly, this requires scientific models, including realistic assessments of uncertainty. The most sophisticated approach currently available, BACIPS, involves prolonged studies of a number of control zone(s) in addition to the SeaZone. Even if the real world conditions of the SeaZone do not allow for a perfect application of the BACIPS ideal, its rigorously scientific approach will guide environmental policy.

3.3. Environmental assessment of floating infrastructure

To determine the effects of a new development on the environment, appropriate ecological metrics must be identified. Such metrics (hereinafter referred to as "environmental parameters") include physico-chemical characteristics like temperature, humidity, sunlight/radiation and dissolved oxygen and biological characteristics. These environmental parameters are always directly, indirectly, positively or negatively influenced by human activities and the built environment. Impacts influence key ecosystem functions, such as photosynthesis, carbon capturing, habitat, etc..[6]

In this report, some of the relevant environmental parameters are listed in physical, chemical and biological categories in Table 3.1. These parameters are discussed throughout Chapter 4 to 12. It should be noted that species abundance and biodiversity are the example environmental parameters in the biological category. A more complete and specific list, with particular relevance for French Polynesia (e.g., coral reef ecosystems), will be determined and studied in depth in collaboration with FIRST Consortium.

[6] social, economic, and cultural parameters are also vital considerations but are outside the scope of this document

Table 3.1: Relevant environmental parameters (Ch.: Chapter)

Physical	Chemical	Biological
- Underwater light (Ch.4) - Water temperature (Ch.5) - Suspended matter & turbidity (Ch.6)	- Dissolved oxygen (Ch.7) - Nutrients (Ch.8) - Seawater alkalinity (pH) (Ch.9) - Toxic substances (Ch.10)	- Community structure & species abundance and diversity (Ch.11) - Animal behavior (Ch.12)

The environmental impact of floating infrastructure involves interaction of different components of the ecosystem with human activities, together forming a "social-ecological system". In this chapter, the characteristics of floating infrastructure that could influence different environmental parameters and ecosystem functions are presented and discussed. Guidelines and design recommendations are given to reduce the negative impacts and increase positive impacts of floating infrastructure in a given location.

Each parameter listed in Table 3.1 is treated in the following chapters, providing information on:

- characteristics of floating infrastructure that might influence the parameter
- a (possible) impact assessment in relation to the parameter, taking into account vulnerability of habitat types and ecosystems
- the design recommendations to reduce negative and increase positive impacts and recommendations for monitoring efficacy of these measures and potential for adaptive management

The information included is based on an initial review of the current state of the science related to the effects of floating infrastructure on freshwater and marine ecosystems. In addition to relevant references, we identify knowledge gaps that appear to require new research. **Each chapter, however, will require further review by relevant experts with particular knowledge of the French Polynesian ecosystems.**

The impact assessment for each parameter is presented in a table (Table 3.2) with scores indicating the: (1) spatial extent, (2) magnitude, (3) duration and (4) probability/frequency of the impact.

Spatial extent relates to the area that will be affected and is classified as 'small', 'medium', or 'large'. A small extent is limited to the size of the floating structures, which are intended to cover < 1% of the SeaZone's total area. The medium extent refers to a size less than 10% of the area that is affected, and a large extent is between 10 and 100% of the total area (see Figure 3.2 in Chapter 3.4). The **magnitude** is the intensity of a threat or benefit. **Duration** describes the time over which the impact is happening. For example, the floating infrastructure has a long duration, while the presence of a boat might be short. The **probability/frequency** addresses how likely or often an impact will occur. For example, the probability/frequency of shadows from floating platforms will be daily (high).

Table 3.2: Overview of key parameters

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

3.4. Project scale

A definition of the intended scale of the floating infrastructure in a SeaZone, including phases up to final total build-out, is necessary for assessing its likely impacts.

For the first SeaZone in French Polynesia, only a limited physical manifestation is envisaged. For the purposes of this document, we consider a likely site on the south side of Tahiti. Here the width of the lagoon varies between 0.5 and 2 km and the larger lagoons measure 600 to 1000 km^2 between passes. The pilot SeaZone involves approximately 7.5 Ha with 12 platforms projected to require about 0.1% (0.75 Ha) of the total space (see Figure 3.2). This means that within the SeaZone, the density of platforms will be 10%. The open water around it will allow light and air to enter the water column. The project will be located in the deeper areas (20-40m), which has lower coral colony density and minimizes the risk of platforms hitting the bottom.

The construction of the floating infrastructure will ideally take place on nearby land, in order to prevent and control emissions and other types of construction related impacts (e.g., noise).

In terms of functions of the floating infrastructure, we assume that uses are limited to those typically allowed in urban settings, and will not include heavy industry or industrial scale agriculture (or aquaculture). Gardens and 'urban farming' are possible, as long as they are within a contained environment (where effluents and organic waste can be treated to a similar level as the domestic waste and wastewater).

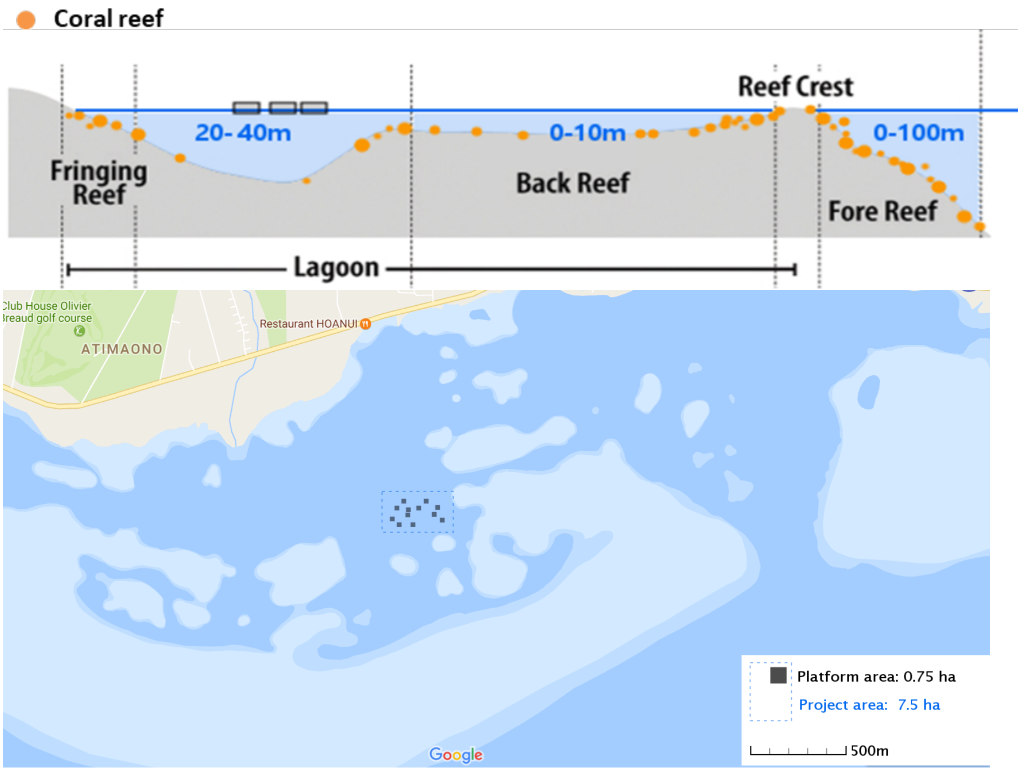

Figure 3.2: Platform area projected

4. Underwater light

Floating infrastructure diminishes incident sunlight on the water column and benthos. The shadow created will move along with the (apparent) daily trajectory of the sun. The objective for floating infrastructure in French Polynesia is to choose an appropriate platform size and density to prevent permanent shading of any part of the seafloor throughout the day. Impact of reduced sunlight duration and/or intensity must also be assessed in relation to the biology of the species affected and any ecological consequences. For instance, floating structure can act as an aquatic animal attracting device because it offers protection in an environment where structure is limited or non-existent. The movement of light and shadow can help create visual uncertainty for predators and therefore, shaded areas form high quality new habitats.

Floating infrastructure will also introduce artificial lighting, such as street lighting, interior lighting, and lights from vessels or vehicles. The impact of such artificial lighting on the surrounding ecosystem must be considered.

Ecosystem vulnerability

Sufficient underwater sunlight is crucial for primary production of ecosystems. Light levels and shadows may also influence animal behavior, including foraging, predator–prey dynamics, orientation, habitat selection, diel vertical migration and other circadian rhythms. However, shadows by no means prevent ecosystems from thriving. Clouds, mountains, trees, rocks and many other obstacles create shadows on a daily basis, and they may be essential to species in order to escape predators, prevent damage from UV radiation, or mitigate other impacts that may result from extreme exposure to sunlight and heat (such as coral bleaching).

Artificial light pollution presents an important challenge for coastal developments in general and in particular for the project, as it may affect behavioral patterns of species.

The following threats and opportunities potentially affecting underwater light conditions have been identified:

1. Floating platform underwater shading
2. Artificial light

These aspects will be evaluated in the following sections.

4.1. Floating platform underwater shading

Floating objects reduce the light that can enter the water column. The platforms and structures will reflect the light and some of the light may be absorbed by the structure. The part of the ecosystem that is directly under the platforms may experience shading during a certain part of the day. The duration of shading depends on the size of the platforms, the orientation, and the depth at which the shadows are evaluated. Depth readings indicate that the lagoon basins on the south side of Tahiti have a depth of 20 to 30m (and specific parts are as deep as 40m). For floating platform sizes that are equal to the depth (20-30m), there will be no long-term or permanent shading at the lagoon floor. Because of the sun's path across the sky, the shadow under the platform will move from west to east. The area directly under the platform will still receive light during 60% of the day (assuming 12h from sunset to sunrise). The adjacent area in east and west direction will receive light during 75% of the day. In addition, in some cases, reflection of light from the building into the water may increase the light intensity around the platform.

In Figure 4.1, time and location of the sea floor that is shaded for "a platform size in relation to the depth" is illustrated. In addition, temporal and spatial range of shadow cast by a floating platform is modeled and demonstrated in Figure 4.2. It should be noted that the model here neither takes into account physical properties (e.g., temperature, turbidity), nor chemical characteristics of water quality yet (e.g., pH, dissolved oxygen).

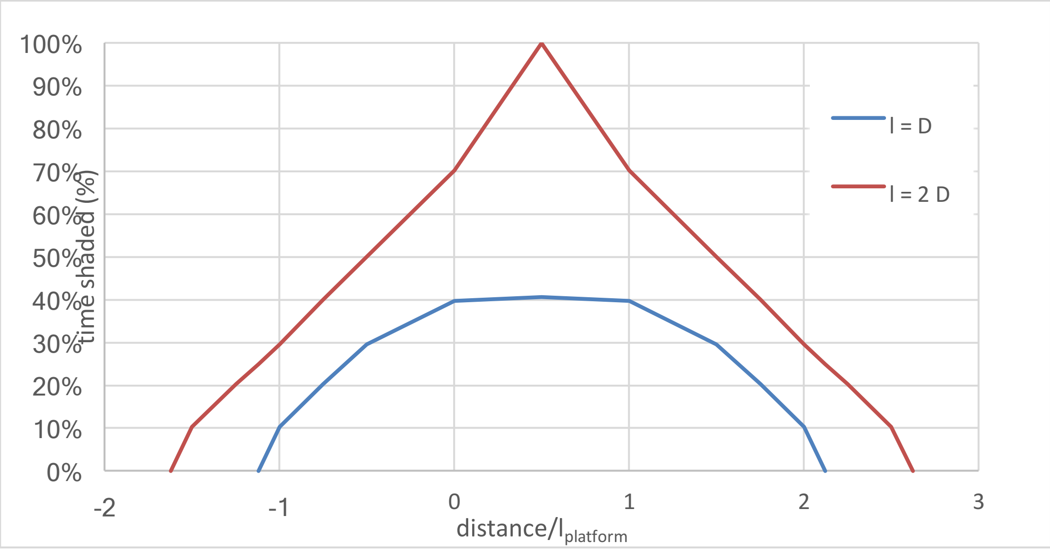

Figure 4.1: Time and location of the sea floor that is shaded for a platform size equal to the depth (blue) and a size of twice the depth (red). Time is expressed as percentage of the day and distance is relative to the platform size. Platform is located between 0 and 1.

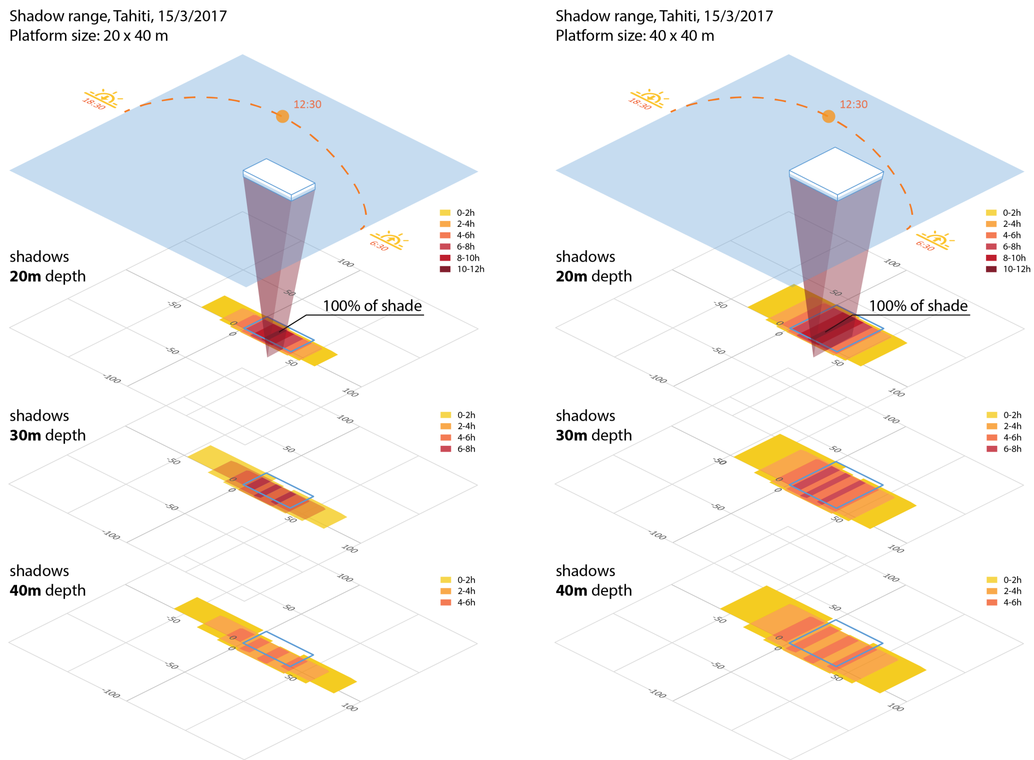

Figure 4.2: Shadow range for two platforms at different water depths in Tahiti, French Polynesia. The darker the color, the longer the shading period at the bottom of the sea.

Daylight entering the water column is crucial for photosynthesis that forms the basis of the trophic structure, but available literature indicates that reductions in light intensity do not necessarily have negative impacts. Such reductions happen naturally on a regular basis, depending on cloud cover and the presence of high obstacles such as mountains and trees that may limit light during certain parts of the day. Minimum light requirements of deep-water corals can be as low as 1% of the incident light (Erftemeijer et al., 2012) and even shallow water species may reach optimum photosynthesis at levels well below the maximum available light (Riddle, 2013). Shallow corals were found to dissipate 4 to 24 times more light than what is used for photosynthesis (Brodersen et al., 2014; Gorbunov et al., 2001). An investigation in Hawaii indicated that the photosynthetic saturation of various coral species already occurred at half of the average light intensity (Riddle, 2004). During high temperature events, corals can even benefit from a reduction in light intensity. Although this phenomenon is partly related to light availability, it is further discussed in the section about 'water temperature.'

Even under more extreme shading conditions, ecosystems show considerable resilience: Campbell and Baird (2009) studied shadowing effects of residential docks in two lakes in Florida and found a reduction in lentic macrophytes of 55% and 70% due to light reduction of 86% and 93%. Rogers (1979) studied a 20 m² area in San Cristobal Reef in Puerto Rico and found that after 5 weeks of complete shading (with black plastic) most corals were damaged beyond recovery, but coral near the edges, which received "some light during the experiment" appeared undamaged. His findings indicate that permanent shading can have considerable impact on the environment, but areas with less permanent shading could avoid impact.

In the lagoon of Tahiti, turbidity levels are moderate, except for areas near rivers that carry sediments and nutrients. In terms of primary production, such areas are not likely to be characterized by rich coral colonies, because freshwater, sediments, nutrients and higher flow velocities inhibit their growth. This is evident from the fact that many passes in the barrier reef coincide with rivers.

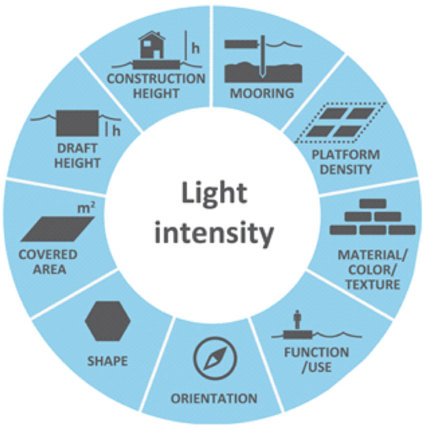

Figure 4.3: Project characteristics possibly affecting underwater light intensity (in blue)

Impact assessment

The platform footprint, shape, draft and orientation, the construction height above water, the platform density, the type of mooring and the color of structures above and below water influence the extent of the volume of water where the light intensity is changed. The magnitude of the impact, corresponding to the change in light availability, is related to location characteristics such as water depth and the light attenuation coefficient of the water.

An overview of the impact assessment is presented in Table 4.1.

Table 4.1: Impact assessment of floating platform underwater shading

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

The spatial extent is limited mostly to the relatively small size of the platforms. The same accounts for the magnitude, the shadows cast will not cause harm to the aquatic life, if can even have a positive benefit. The duration is *medium*, during the whole day shadows will be casted, however these shadows will be moving around. Shadows will also be cast every day, which makes the frequency *high*.

4.2. Artificial light pollution

Minimizing artificial light pollution at night is important, as research indicates that such light sources (e.g., coastal development, shipping or offshore infrastructure) can affect and potentially disrupt the behavior of wildlife (e.g., Ugolini et al., 2005; Brüning et al., 2011; Riley et al., 2012; Riley et al., 2013). The interference of artificial light with natural light cycles can have a negative impact on species (e.g., disorientation, disturbed metabolism and reproduction) and can change the balance of food webs (altering predator-prey relationships) (Davies et al., 2015; Held et al., 2013; Perkin et al., 2011).

Light levels at night should be minimized both for the environment and for the inhabitants. Typical levels for pedestrian areas between 3 and 10 lux. At 10 lux (originating from 5m away), it would be perceived as moonlight (0.1 lux) at a distance of 50m.

It is reported that many coral reef fish species exhibit little or no visual sensitivity to spectral wavelengths above 600nm (orange light) (Horodysky et al., 2010; Job and Shand, 2001; Marshall et al., 2003). Therefore, to mitigate impacts, outdoor lighting at wavelengths that are less likely to disturb fishes can be used. Orange and red light are known to reach only limited depths (at 1 m depth red light intensity is already reduced by 90%, and orange light by 50%) and the higher end of the light spectrum (e.g. LPS and Amber LED) was found to have much lower effect on melatonin suppression, photosynthesis and starlight visibility (Aubé et al., 2013). As a result, warm lighting options are less likely to reach or influence marine species.

Impact assessment

The presence of human activities on floating platforms can affect light intensity. At night, excessive artificial lighting from street lights, buildings, vehicles or boats can disturb wildlife. The extent of the impact corresponds to the area influenced by artificial light, which depends on the platform footprint and density and the use/function of platforms and on other project characteristics, such as the presence of windows and shutters. The magnitude of the impact corresponds to the intensity of artificial light that is emitted and the duration and timing of light emission. Artificial light is limited to the area where the light penetrates the water. The magnitude will be *low*, because of the limited impacts and water penetration of red and orange light. Duration will be at night, and most likely not all night long. The use of light will occur on a daily basis, as long as there are people present, resulting in *high* probability/frequency.

An overview of the impact assessment is presented in Table 4.2.

Table 4.2: Impact assessment of artificial light pollution

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

4.3. Design recommendations

The light requirements of the local fauna, the water depth and the light attenuation coefficient will define the design of the floating infrastructure within a SeaZone. The light intensity in the vicinity of the floating infrastructure should be modeled, allowing to adapt the design and location of the floating platforms and the structures on the platforms, until the underwater light intensity does not fall below the optimum light intensity for minimizing local photosynthesis and disturbance of wildlife. The precise boundaries (tolerance) for light reductions (due to shading) or increases (due to artificial light sources) will be defined in the final EIA.

In general, smaller, long and slim platforms with a small draft should be used. The area that is shaded by the floating platform through the inhibition of direct light can either be minimized (smaller, long and slim platforms with a small draft), if indirect light is not sufficient for local photosynthesis, or maximized, in order to increase the area of reduced heat stress. The orientation and construction height of the floating infrastructure can be changed in order to adapt the size of the shadow. Floating structures that can move/rotate according to the sun could also be interesting to consider. For example, structures that rotate around a pivot point could be evaluated to determine if they can provide benefits to the underwater light. Awnings could be used to increase the extent of the shaded area during high temperature events that could threaten reef health (i.e., bleaching).

The best way to mitigate the negative effect of artificial light pollution is to minimize the use of light at night, whenever possible. A big part of the lighting used today is not efficient as it illuminates areas unnecessarily. Other measures such as installing motion sensors, illumination codes, or the use of lamps with specific wavelengths (to cause the least effect on nocturnal organisms), are solutions that can minimize light pollution. This accounts for both the outdoor lighting and the lights used indoors that can illuminate the water surface.

4.4. Monitoring recommendations

The effects of shading during the day and of the light emitted during the night should be considered when monitoring ecological processes and appropriate benchmarks developed with acceptable boundaries for specific areas/times.

5. Water temperature

The objective for floating infrastructure in French Polynesia is either to have no significant influence on the average water temperature of the SeaZone, or to reduce the average water temperature to keep it within the tolerance range of the local organisms. A small reduction of the water temperature is likely to be beneficial, rather than harmful, in view of the challenges of climate change. Rising sea surface temperatures are already causing more frequent coral bleaching events in many places (Baker et al., 2008; Hughes et al., 2017).

The following potential threats and opportunities have been defined in terms of changes in temperature:

1. Floating platform effects on temperature
2. Air conditioning effects on temperature

These aspects will be evaluated in the following sections.

Ecosystem vulnerability

In tropical lagoon ecosystems, a stable water temperature with minor variation is crucial. Significantly lower temperatures could cause a reduction in the growth of phytoplankton and macrophytes and a reduction in the rate of photosynthesis. On the other hand, significantly higher temperatures increase metabolism, respiration and oxygen demand and can also reduce the rate of photosynthesis. The increase in global ocean temperatures is already threatening delicate ecosystems such as coral reefs, leading to more frequent bleaching events (West and Salm, 2003). The solubility of dissolved oxygen, carbon dioxide, salts and many other substances is also affected by water temperature.

5.1. Floating platform effects on temperature

The temperature balance of a water body is a complex system. During the day a large part of the solar radiation heats up the water column. This heat is lost again throughout the day and night, due to convection, conduction, evaporation and thermal radiation. When a floating structure is introduced, the solar radiation that hits the structure is prevented from entering the water column.

Water surfaces have a low reflectivity of 4-12%, which means that 88% to 96% of the sunlight enters the water column. Although shallow lagoon areas (<5m) with a sand bottom offer some reflectivity (albedo of 20-35%), deeper areas and other types of bottoms will result in much lower reflectivity (albedo of 0-10%) and especially the higher wavelengths are absorbed (>600nm) (Maritorena et al., 1994). This is the reason that the lagoon surface appears to be blue to turquoise. The light that is not reflected is converted into heat (except for a negligible fraction of energy that may be diverted to primary production of <0.1%).

The incoming solar energy that enters the water column is lost again during the day and night. Evaporation is responsible for removing nearly half of the added energy, and thermal radiation also removes a considerable part. Other heat transfer processes include conduction, convection and the influence of lagoon currents, rain and river runoff. The absence of solar radiation during the night leads to diurnal temperature cycles in the water. In lagoons in nearby Moorea, this daily temperature difference ranges from 0.5 to 4 °C (Putnam and Edmunds, 2008). During hot and calm weather periods, less heat will be released from the water causing it to warm.

The project will only cover a small area of the total water surface and lagoons with passes nearby are often flushed at a relatively high rate. For example, residence times estimated on the order of hours to days in neighboring island Moorea (Nelson et al., 2011). Residence times will need to be estimated for the actual SeaZone site.

When covering the water surface with a floating platform, no solar energy will be absorbed by the water directly under the platform. The light that falls on the platform will be partly reflected and partly absorbed and converted into heat. This heat will be emitted to the air and only a small part is transmitted to the water (depending on the conduction of the platform). During the day, this will provide relative cooling to the water under the platform. Assuming that all of the solar energy on the platforms would be averted (~20 $MJ/m^2/day$), the project could prevent 0.5 °C of added heat per day, averaged over a water depth of 10 meters under the platforms (without taking into account water flow and heat transfer). This is comparable to results of Foka (2014) that concluded average water temperatures in the first meter of the water column are slightly lower (around 0.5 °C) in the proximity of floating houses, compared to open water.

Taking into account a moderate flow velocity of 0.05 m/s it would take 10 minutes for a water particle to pass the platform. During this time about 300 kJ/m2 of heat could be avoided, preventing the first 10 meter of water from heating up by 0.007 °C.

At the scale of a lagoon basin of 50 million m^3, the effect will not be noticeable (<0.001 °C/day) and would only persist as long as the residence time of the water (order of hours to days).

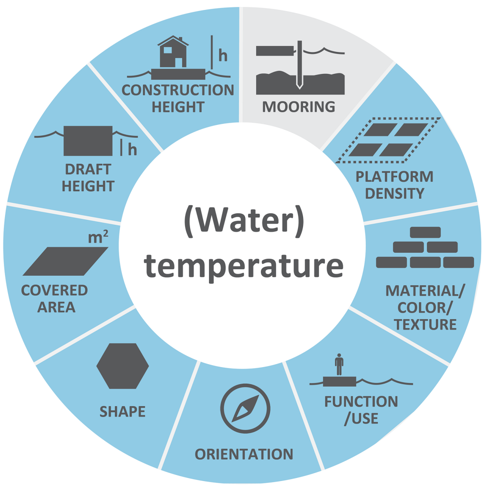

Figure 5.1: Project characteristics possibly affecting (water) temperature (in blue)

Impact assessment

A small reduction in temperature is not likely to affect this type of ecosystem because the main threat is elevated temperature that can cause coral bleaching. In periods of warm and calm weather, when the lagoon is more stagnant and water temperatures become elevated, the slight cooling effect could potentially offer some relief to local species. In past decades, warmer seawater temperatures and more frequent coral bleaching events have been recorded in Moorea and other places (Penin et al., 2007; Pratchett et al., 2013). Many species and specifically corals are very vulnerable to increases in temperature, since they usually live close to their upper limit of thermal tolerance (Berkelmans and Oliver, 1999). Multiple studies have shown, that a reduction in solar radiation during temperature stress events can prevent corals from bleaching, for example by shading through steep reef walls (Fabricius et al., 2004), turbidity (Cacciapaglia and van Woesik, 2016), mangroves (Yates et al., 2014), clouds (Mumby et al., 2001), high islands, rocks or clouds (Grimsditch and Salm, 2006; Marshall and Schuttenberg, 2006).

The cooling effect of floating platforms, if significant at all, will mainly be noticeable during the day and will not result in result in extreme temperature differences. A cloud that blocks the sun is likely to have a larger effect on water temperature, and cooling during the night will definitely be more significant.

The cooling of the water also depends on the water exchange rate. When the water is exchanged frequently, significant cooling is unlikely to take place. The extent of the area that is shaded but not directly beneath the floating development depends on the platform footprint, draft, shape, construction height, platform density and orientation. The magnitude of the impact corresponds to the absolute change in local water temperature, which depends on the water exchange rate. Both are expected to be *low*. The duration will be during the day when the water area is shaded, and is considered *medium*. The probability/frequency is every day, and for this reason is *high* (Table 5.1).

Table 5.1: Impact assessment of floating platform effects on temperature

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High (selected)
Medium	Medium	Medium (selected)	Medium
Small (selected)	Low (selected)	Short	Low

5.2. Air conditioning effects on temperature

Many homes in French Polynesia do not have air conditioning. Depending on the location and design of buildings, the cool ocean breeze, supplemented by fans, can provide sufficient cooling. Some air conditioning, however, is likely on most floating infrastructure in tropical climates and it could lead to a change in temperature in the environment. Electrical indoor cooling will transfer thermal energy to the environment where it can heat up the air, and to a much lesser extent, nearby water bodies.[7]

An interesting option for sustainable cooling in Polynesia is Seawater Air Conditioning (SWAC or mini-SWAC), which has been pioneered by Pacific Beachcomber SA at the Intercontinental Hotel on Bora Bora and The Brando on Tetiaroa. Between water depths of 150m to 400m, temperature in the waters around Tahiti drops from 25°C to 5 ± 2°C (Rougerie et al., 2004). SWAC uses cool, nutrient rich water from these layers for cooling and aquaculture applications. A study for the Honolulu SWAC project predicts significant environmental benefits such as water saving and carbon dioxide emission reduction. Despite the environmental benefits, the potential environmental impacts of returning cooler and nutrient-dense deep ocean water close to the ocean surface must be addressed (Lilley et al., 2012). If deep sea water is used to provide cooling to temperatures between 20 and 25 ºC, there is a risk that the returning water is still relatively cool compared to the water temperature of the lagoon. It is also rich in carbon and nutrients. For this reason, the discharge is typically outside the reef and not at the surface but deeper to approach ambient temperature. There are potential uses for the cold that remains in the water, as well as for the carbon and the nutrients. These dual-uses of SWAC (which include food production) are the subject of active research, particularly through the Tetiaroa Society, which operates a research facility plumbed with deep ocean water from The Brando resort's SWAC. Tetiaroa Society hosts international and local scientists – particularly those involved in the FIRST Consortium.

Impact assessment

The extent of the impact corresponds to the area that is influenced the effluent of SWAC and the magnitude of the impact corresponds to the volume and temperature of effluent, which depend on the design of the conditioning systems. The extent is medium or large depending on the size of the SWAC. The magnitude is also something that still needs to be researched. Ideally, SWAC might be used to reduce excessive warming to protect sections of reef from bleaching - this is the subject of ongoing research and development. The magnitude and extent are expected to be between small and medium. The duration of the effect will be not only when the SWAC produces effluent, if coral bleaching is reversed this effect can remain longer and even restore areas. Because little research has been done to date, it is now estimated to have a medium effect; this also applies to the probability/frequency (Table 5.2).

[7] To create an indoor climate that is 5 ºC cooler than the outside temperature, a similar volume of outside air will need to be heated by 5 ºC (or 5 times this volume heated by 1 ºC. In addition, an air conditioner in a typical home uses about 10MJ per day of electricity that is converted into heat. Enough to heat 4 more homes by 5 ºC. The effect on the water temperature is relatively small, 50 homes (or equivalent space) on a water surface of 1 hectare could heat up the water by 0.0015 ˚C/day, assuming a depth of 10 meters. Compared to the shadowing effect, air conditioning will be 80 times less significant.

Table 5.2: Impact assessment of air conditioning effects on temperature

Spatial extent		Magnitude		Duration		Probability/frequency	
	Large		High		Long		High
	Medium		Medium		Medium		Medium
	Small		Low		Short		Low

5.3. Design recommendations

Buildings that will use air conditioning should have sufficient insulation (bioclimatic design principles) in order to keep the coolness inside the buildings and maximize natural ventilation and other cooling measures.

For SWAC a cost/benefit analysis could be made, taking into account the possibility to recirculate and use water for other purposes within the development. In the design of floating infrastructure, functions can be combined to benefit from each other, minimizing the energy and resource input and maximizing reuse (e.g. combining air conditioning of buildings and aquaculture). If the effluent water is discharged at a temperature and nutrient content that match the ambient, impacts should be negligible.

5.4. Monitoring recommendations

Further research is needed to better understand the influence of floating platforms on water temperature and to give additional design recommendations. A model could be developed in order to predict the influence of floating infrastructure on the water temperature and identify platform characteristics that have a significant influence.

The water temperature should be monitored in order to identify possible temperature fluctuations around the floating project in comparison to open water areas. The data will validate and improve the model used to predict the influence of floating infrastructure on water temperature. Monitoring the temperature in proximity to the SWAC discharge is also desirable.

Following these recommendations, floating infrastructure in French Polynesia need not have any significant influence on the average water temperature of the SeaZone, and there are opportunities (particularly with SWAC) to have a beneficial impact through potential cooling effects that might help maintain local water temperatures within the tolerance range of the local organisms in the face of global warming.

6. Suspended matter and turbidity

Floating infrastructure in French Polynesia should aim to have no significant influence on the suspended matter content and turbidity present in the SeaZone, or to reduce the suspended matter content and turbidity present in the case of terrestrial inputs (pollution) due to human activities on land, helping maintain low sedimentation rates in sensitive areas, such as coral reefs.

Suspended matter refers to the particles and the solids that are drifting and floating in the water column. Solids include both organic (e.g., algae) and inorganic material (e.g., silt and sediments). Pollutants may contribute to suspended matter increasing organic and inorganic solids in the water. Material suspended in water affects water clarity, creating a cloudy or hazy appearance. The cloudiness or haziness of a fluid is referred to as turbidity. Petus et al., (2010) define turbidity as “a decrease in the transparency of a solution due to the presence of colored suspended and dissolved substances.” Turbidity is a measure of relative clarity, whereas suspended matter refers to the amount of solids/particles present in the water column (Fondriest Environmental Inc., 2016a).

During the use of the floating structures, water flow velocity and directions can be altered. This could lead to erosion elsewhere. The presence of structures can also cause sedimentation. For water bodies with high turbidity, this can be a benefit, especially when this effect is combined with filter feeders and macrophyte growth, which also increase sedimentation and decrease turbidity. During the installation phase of the mooring systems, production of particulate matter will occur. Less disruptive systems are preferable.

Ecosystem vulnerability

Suspended matter may affect ecosystems reducing the amount of light available for photosynthesis, diminishing visibility for marine organisms affecting feeding and other behaviors. Benthic organisms could be affected by particles falling to the bottom. Depending on the amount of sedimentation, benthic ecosystems could be buried.

As Baynes and Szmant (1989) pointed out, “Sedimentation is harmful to sessile benthic organisms in that it (1) clogs the pores of ascidians and sponges, (2) inhibits polyp feeding, (3) reduces the amount of light reaching zooxanthellae, (4) inhibits the exchange of dissolved nutrients and gases, (5) leads to an

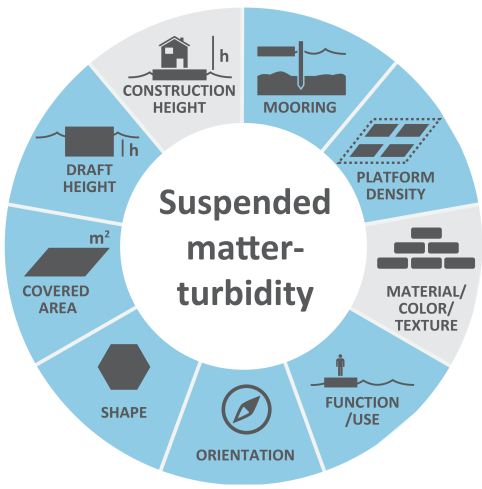

Figure 6.1: Project characteristics possibly affecting suspended matter and turbidity (in blue)

increased energy expenditure due to sediment rejection activities, (6) inhibits planula settlement and development, and (7) physically abrades and buries encrusting organisms." This study associated the lower presence of corals in flat areas with higher turbidity and sediment accumulation.

On the other hand, ecosystems that are not reached by sediments could suffer from erosion and a lack of nutrients. The particle size that remains in suspension within the water column depends on the speed of the current. Fast currents can pick up and transport larger particles, as the current slows down, the heaviest and bigger grains fall out first and the smallest silt particles settle last (Grotzinger and Jordan, 2017).

In locations where the sediment is not stable enough for the establishment of macrophytes, sedimentation of larger particles can lead to the stabilization of the sediment, facilitating the growth of macrophytes. The size and weight of the particles, depends on the material the particles are made of.

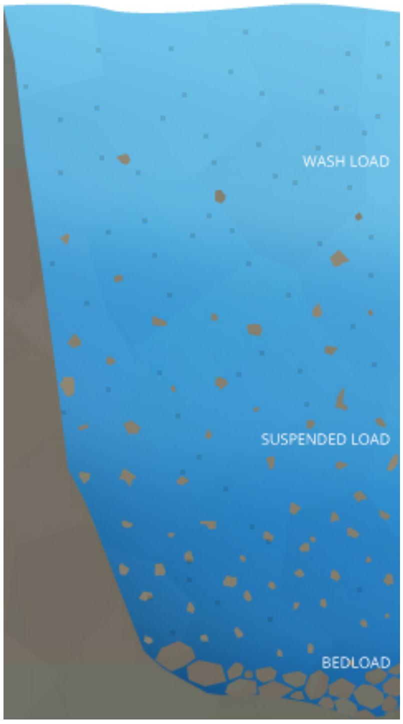

Figure 6.2: Sedimentation in the watercolumn. Source: Fondriest

The following potential threats and opportunities have been defined that can cause changes in suspended matter and turbidity:

1. Interaction of floating platform with water movement
2. Water filtration by filter feeders
3. Macrophyte growth
4. Mooring

These aspects will be evaluated in the following sections.

6.1. Interaction of floating platforms with water movement

Floating platforms could locally slow down or speed up the current, inducing the sedimentation of suspended matter or erosion. The effect depends on several different factors including water speed, depth, currents, amount of sediments and structural characteristics of the platforms, such as draft, shape, etc.

The influence of a floating platform on water movement depends mainly on its width and draft in relation to the prevailing flow direction. The density of the platforms will also play a role. The extent of the impact corresponds to the volume of water where water flow is altered and the suspended matter that will settle and turn into bedded sediment. The magnitude of the impact corresponds to the relative change of direction and speed of the current. The influence of the floating infrastructure on sedimentation is hard to predict. More data is needed about the structures' shape, density, amount of suspended matter currently present in the water column, etc. Therefore, no impact assessment is presented for this topic at this time.

Impact assessment

Due to the clarity of the water, floating platform location in the lagoon and the water depth, the impact assessment for water movement (1) spatial extent - *medium*, (2) magnitude - *low*, (3) duration - *long* and (4) probability/frequency of the impact – *high* (Table 6.1).

Table 6.1: Impact assessment of interaction of floating platforms with water movement

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long (selected)	High (selected)
Medium (selected)	Medium	Medium	Medium
Small	Low (selected)	Short	Low

6.2. Water filtration by filter feeders

Filter feeders can colonize floating platforms. Filter feeders, such as bivalves, feed on particles they filter from the water column, assimilating organic carbon and nutrients. Particles that are not digested are excreted as mucus-bound aggregates, which are larger than the initial particles filtered from the water and settle more quickly (Zhou et al., 2014). The colonization of floating platforms by filter feeders can therefore lead to an increase in the local sedimentation and a decrease in the suspended matter content of the water.

Impact assessment

The extent of this impact corresponds to the volume of water that passes by the platform surfaces colonized by filter feeders, which depends on the platform footprint, draft, shape and orientation to the current. The magnitude of the impact corresponds to the amount of particles filtered from the water per volume of water, which depends on the density of filter feeders, the filtration rate of filter feeders, the current speed, and the sediment content of the water. Filter feeders are very likely to colonize floating platforms. However, extent and magnitude are difficult to assess here, because we have limited knowledge of the local soil and sediments. The duration of the filtration and the probability are both long and high, because the filter feeders are commonly found on floating platforms and will be present for a long time (Table 6.2).

Table 6.2: Impact assessment of water filtration by filter feeders

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

6.3. Macrophyte growth

Photosynthesizing species can benefit from an increase in light intensity through the reduction of the turbidity of the water. The accumulation of bio deposits, including larger particles and whole bivalves detaching from the platform, can lead to the stabilization of the sediment, supporting the growth of macrophytes, such as seagrasses and seaweeds. The presence of seagrass further contributes to slowing down the water movement and trapping sediments (de Boer, 2007).

Impact assessment

The extent of the area where floating platforms can support the growth of macrophytes corresponds to the area that receives larger bio deposits from the platform. The magnitude of the impact depends on the sedimentation rate of bio deposits. When the sedimentation rate of bio deposits is low, the sediment will take longer to stabilize, but even with a very low sedimentation rate, the sediment will eventually be stabilized. The potential of this impact is quite high, areas suffering from turbidity could benefit from this local effect caused by seagrass and filtering organisms. The extent is expected to be limited to the immediate area around the platforms, so *small* to *medium*, the magnitude if the water is highly turbid could become *low*. Duration will be as *long* as the project is present and even beyond. The probability is *high*, as suspended matter is expected to be highly present at estuaries (Table 6.3).

Table 6.3: Impact assessment of macrophyte growth

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

6.4. Installation of mooring poles

Floating infrastructure will most likely deploy mooring systems to keep the structures in place. For structures in shallow areas, mooring poles are common. During the installation of mooring poles, sediments are displaced, increasing the suspended matter content locally. This can also occur in later building phases, while the structures are replaced or dismantled.

The extent and magnitude of the impact depends on the type of mooring system and its installation, and the water movement. The mooring system will need to be fixed into the ocean floor, in order to withstand high forces from the weight of the structures, in combination with currents, tides and storms. The extent will be limited to the area where the installation takes place (*small*), the magnitude will be *medium*, as the water flow in the area is expected to be present and will carry the particles over a longer distance. On the other hand, this large spread of the particles will prevent specific areas from being buried. Duration of the particles being released will be *short*. Also small changes in water movement can occur around the poles, this can take place for a longer time. Both effects have a *medium* probability (Table 6.4).

Table 6.4: Impact assessment of installation of mooring poles

	Spatial extent		Magnitude		Duration		Probability/frequency
	Large		High		Long		High
	Medium	■ (yellow)	Medium	■ (yellow)	Medium	■ (yellow)	Medium
■ (green)	Small		Low		Short		Low

6.5. Design recommendation

The water movement around floating platforms should be modeled, in order to predict areas of sediment accumulation and erosion. When unwanted sedimentation or erosion occurs, based on this model and depending on the acceptable boundaries (benchmarks), the design and location of the platforms should be adapted. Favoring the local accumulation of sediments can reduce the sediment load and turbidity for the rest of the ecosystem, supporting photosynthesis. Floating vegetation with underwater screens could be added to the design of the floating platform, in order to increase the local accumulation of sediments (Lauwerijssen et al., 2015).

An estimation of the sedimentation rate of bio-deposits should be made. If the predicted rate surpasses the sensitivity threshold of the local organisms, the design or location should be adapted. In general, for slim platforms oriented with the longer side perpendicular to the current, the bio-deposits will be spread over a larger area, reducing the sedimentation rate.

In order to support growth of macrophytes and further reduce turbidity, the platforms can be designed to optimize the overlap of the area with sedimentation of large particles with the area that has sufficient light intensity for the growth of macrophytes.

Sediment resuspension and habitat destruction during mooring pole installation can be reduced by choosing less invasive installation methods and minimizing the number and size of poles. A method that was suggested for bungalows in the Bahamas is 'socketing'. Socketing involves the use of a displacement tube that defines the area to receive the piling the material is evacuated by either chiseling or auguring through the displacement tube. This has the net effect of containing all impacts directly to the vicinity of the displacement tube" (Islands by Design, 2012). Next to using less invasive methods, pole amount and size should be minimized. Poles change water flow, redirecting it or speeding it up around them. Also the poles should not be planned in the middle of corals, but designed around them in sandy areas.

6.6. Monitoring recommendations

Monitoring of suspended matter and measuring water turbidity can give insight on the effects that floating structures have on sedimentation/erosion patterns at the location and help refine circulation models. Taking sediment samples with decreasing distance to the center of the floating platforms can provide insights on the levels of suspended matter and on the extent of the impact. Sedimentation rate can be measured with sediment traps.

7. Dissolved oxygen

The objective for floating infrastructure in French Polynesia is to either have no significant influence on the average dissolved oxygen (DO) content of the SeaZone, or in case of an already degraded environment, to increase DO to a sufficient level for the local fauna. Floating platforms may have various effects on dissolved oxygen:

- the area that is occupied by floating platforms will no longer allow oxygen exchange between air and water,
- splashing of the water against the sides of the platforms will allow additional oxygen to enter the water column - larger platforms are likely to produce more turbulence (smaller platforms follow the waves),
- organisms that are present under the platforms consume oxygen, whereas photosynthetic marine species living at the seafloor or sides of the platforms produce oxygen during the day.

However, the largest influence on dissolved oxygen levels under floating platforms remain the local conditions, such as wind and wave regimes and water flow.

Ecosystem vulnerability

Dissolved oxygen is a parameter that refers to the free, non-compound oxygen present in water. Oxygen enters the water through the air (by diffusion and aeration, induced for example by wind) and through photosynthesis of phytoplankton, algae and plants.

Dissolved oxygen is necessary for organisms to respire. If the dissolved oxygen is too low or too high, aquatic life can be harmed. When oxygen drops below a certain level, the rate of fish mortality rises (Fondriest Environmental Inc., 2016b). The vulnerability of the ecosystem to this impact depends on the oxygen demand of the ecosystem, the production rate, and the importance of diffusion in the oxygen cycle.

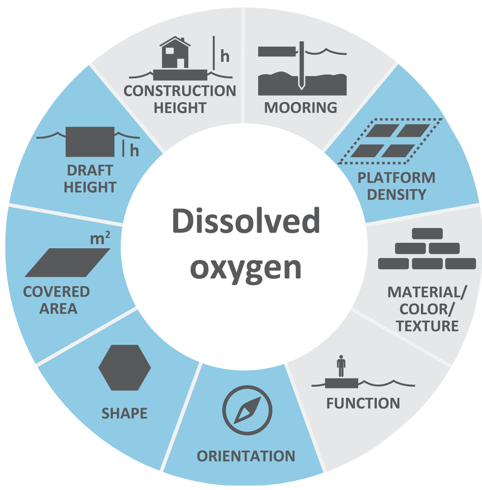

Figure 7.1: Project characteristics possibly affecting dissolved oxygen (in blue)

The following threat could affect dissolved oxygen:

1. Presence of floating structures

7.1. Presence of floating structures

The presence of floating structures might affect dissolved oxygen levels. In the event that 1) water movement is limited, 2) sessile organisms that colonize the bottom of the platforms consume available oxygen, and 3) oxygen production by photosynthetic organisms is reduced: dissolved oxygen below the platforms is likely to decrease. Water quality measurements by de Lima and Sazonov (2014) at several floating infrastructure locations in the Netherlands showed that dissolved oxygen levels below floating structures are between 0 and 10% lower compared with nearby open water conditions, and that reductions in dissolved oxygen seem to correlate with shallow and relatively stagnant water. Numerical modeling of dissolved oxygen under floating platforms suggests that for situations where advection is negligible (stagnant flow), oxygen levels are likely to be 10% lower under floating buildings (Foka, 2014). Both studies were done in fresh-/brackish water situations with limited water movement. In a marine lagoon environment, where the water movement is usually higher, the difference between oxygen level in proximity of floating infrastructure and oxygen levels in the open water will likely be smaller.

Impact assessment

The impact of floating structures on dissolved oxygen levels will be limited. Measurements in stagnant freshwater of limited depth indicate that dissolved oxygen levels under platforms can deviate by 10%. Water flow velocity can have a considerable influence on oxygen distribution. Even at a flow velocity of 0.05 m/s, it would take less than 10 minutes to replenish any consumed oxygen under a 25m wide platform. Therefore, the magnitude of the impact is rated '*low*'. In terms of the extent, any impacts on dissolved oxygen will be localized to the area underneath and in the immediate surroundings of the platforms. The duration of this effect will be as long as the floating structures are present, the probability is rated as '*medium*', considering very limited data is currently available on oxygen levels underneath platforms in marine environments (Table 7.1).

Table 7.1: Impact assessment of presence of floating structures

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

7.2. Design recommendations

In most locations, lagoon water flow is likely to ensure that dissolved oxygen levels under the platforms are close to the level in surrounding areas. Lower levels of oxygen are possible if high numbers of species have colonized the platforms and water is nearly stagnant. In order to ensure sufficient light levels under the platforms, open water will be available around the platforms, which will also benefit oxygen exchange. This will minimize the maximum distance water travels under the platform. Platform size will affect the amount of splashing, which contributes to aeration. Platform sizes that are over twice the dominant wavelength will be more stable, and instead of moving along with the wave motion they will interact with incoming waves, resulting in splashing.

Another way to increase oxygen content in water is to place submerged floating wetlands near structures. Floating wetlands can use lightweight floating structures as support and buoyancy, growing their roots directly into water. Macrophytes on floating wetlands mediate the transfer of oxygen from air to water, releasing oxygen through their roots (Brix, 1997). In addition, floating wetlands adsorb nutrients from the water and provide habitat for wildlife. If necessary, other measures to increase dissolved oxygen in water could easily be introduced.

7.3. Monitoring recommendations

It is recommended to perform measurements of vertical profiles for dissolved oxygen concentration throughout the day and for long periods (preferably one year). Long-term data allows for capturing the seasonal variability of the system. Local wind speed and wind direction measurements between the floating structures and in the open space should be taken. Such measurements will assist in identifying a potential relation between the increase of wind speed (wind tunnel effect) and Dissolved Oxygen variations. Finally, monitoring of the vertical profile of plant biomass can help identify the contribution of photosynthesis to the amount of dissolved oxygen (Foka, 2014).

8. Nutrients

The objective for floating development in French Polynesia is to either have no significant influence on the average dissolved nutrient content of the SeaZone, or in the case of existing pollution, to decrease the average dissolved nutrient content to levels that favor ecosystem health.

Nutrients will typically be produced during the operational phase of the floating infrastructure. Inhabitants and visitors should be made aware of the health and environmental issues related to throwing waste into the water. This includes plastics, wastewater, detergents, and organic waste. Moreover, sewage effluent will need to be fully recycled and the remaining nutrients extracted from it (and reused for other purposes).

Ecosystem vulnerability

Nutrients support primary producers, which in turn sustain species on higher trophic levels. In an aquatic environment, primary production is performed by species such as phytoplankton, macrophytes, and corals, and the organic matter is transferred to different trophic levels of the ecological pyramid (see Figure 11.1, chapter 11).

Both too low and too high nutrient concentration can have negative effects on the ecosystem. Low nutrient concentrations as well as the unbalanced ratios (e.g., between nitrogen and phosphorous) can reduce available food quality and quantity for marine organisms. High nutrient concentrations might cause excessive phytoplankton growth. Furthermore, when phytoplankton dies, the quantity of organic matter being decomposed increases oxygen consumption, which can lead to oxygen depletion and eventually the death of benthic animals and fish.

The vulnerability of the ecosystem to this impact depends on the sensitivity of organisms to increased nutrient loads. Some organisms, such as phytoplankton, could benefit from high levels of phosphates and nitrogen in the water. However, for many other organisms, these algae blooms represent a threat.

The following potential threats and opportunities have been defined in terms of change in nutrient availability:

1. Wastewater effluent treatment
2. Malfunctioning of wastewater treatment
3. Water filtration by filter feeders
4. Bio-deposition by filter feeders

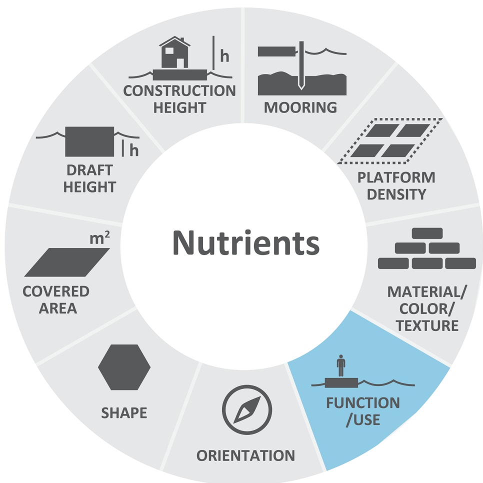

Figure 8.1: Project characteristics potentially affecting nutrients (in blue)

These aspects will be evaluated in the following sections.

8.1. Wastewater effluent treatment

Wastewater effluent is a major source of nutrients, as has been demonstrated in some floating informal settlements, usually found on inland waters near large cities, which have no wastewater treatment at all. If wastewater effluent is not properly treated it can lead to an increase of the nutrient content of the water. This is generally not the case for floating infrastructure in countries like the Netherlands, where the structural design must comply to strict rules and regulations and that wastewater should be treated and reused.

A sewage treatment system, whether floating or on land, should be included in the design of floating infrastructure. The current treatment level of the new wastewater plant in Papeete is listed in Table 8.1. For comparison, the required treatment level of ships in international waters is also shown - conventions on wastewater effluent from ships, MARPOL, annex IV (The Marine Environment Protection Committee, 2012). By using widely available on-board sanitation technology, such as a membrane bioreactor (MBR), biofilm or electrolytic wastewater treatment systems, effluent from floating infrastructure could easily exceed the treatment levels currently required by French Polynesia's environmental code.

Table 8.1: Comparison of the treatment level in French Polynesia and MARPOL wastewater plants

	FP (Code Envmt.)[8]	MARPOL (annex IV)[9]
5-day BOD (DBO5)	<30 mg/l	<25 mg/l
COD (DCO)	<120 mg/l	<125 mg/l
TSS (MEST)	<35 mg/l	<35 mg/l
Organic carbon	<70 mg/l	
Nitrogen (total)		<20 mg/l (or 70% reduction)
Phosphorus (total)	< 10 mg/l	<1 mg/l (or 80% reduction)

Impact assessment

The objective for floating infrastructure projects in French Polynesia is for wastewater to be filtered to *at least* the standards of French Polynesia and MARPOL. In the optimal situation, the wastewater will be fully reused and applied in a closed circular system.

The spatial extent for the basic water treatment facility (exceeding MARPOL standards) would have a *medium* extent, as the treated effluent would have a larger affected area than only the platform; however, compared to the size of the SeaZone, it

[8] Source: DIREN (2016)

[9] Source: The Marine Environment Protection Committee (The Marine Environment Protection Committee, 2012)

will still be not that large. The magnitude will be *low* because of the water flow and the connection between the water body with the open ocean. The duration is *long*, as the effluent will be produced on a regular basis during operation, and the probability is also *high* - while people are living on the platform, wastewater will be produced (Table 8.2).

Table 8.2: Impact assessment of wastewater effluent treatment

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

In the case of optimal water treatment, a closed loop system where all the water is reused, the extent and magnitude will be *small* and *low*. The duration is *long* and the probability is *high* (Table 8.3).

Table 8.3: Impact assessment of optimal wastewater effluent treatment

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

8.2. Malfunctioning of the wastewater treatment

Wastewater treatment malfunctioning would have an impact on the environment. Ideally, the structures will be equipped with an additional buffer that can store the additional wastewater in the event of a malfunction. Moreover, the systems should be equipped with a warning system. If spills occur despite these measures, both the extent and magnitude are expected to be *medium*, the duration *short* and the frequency very *low*.

Table 8.4: Impact assessment of malfunctioning of the wastewater treatment

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

8.3. Water filtration by filter feeders and macrophytes

If filter feeders colonize the floating platforms, they will filter small particles from the water. This can be a benefit for the ecosystem, since it reduces the turbidity, nutrient content and pollution of the water and focuses sedimentation under the platforms, reducing sedimentation downstream (see Chapter 6). Bivalves feed on particles that they filter from the water column, assimilating the organic carbon and nutrients. Particles that are not digested are excreted as mucus-bound aggregates, which are larger than the initial particles filtered from the water and settle more quickly (Zhou et al., 2014). Pathogens within the particles filtered from the water column can be bio-accumulated and inactivated by the bivalves (Slodkowicz-Kowalska et al., 2006). This leads to better water quality.

In a recent study, the abundance of bacterial pathogens was decreased by 50% through the presence of seagrass meadows. Corals located adjacent to the seagrass meadows showed a 50% reduction in disease prevalence compared to paired reefs without adjacent seagrass meadows (Lamb et al., 2017).

The extent of any such benefits would correspond to the rate and volume of water that passes by the platform surfaces colonized by filter feeders, which will increase with the total area of the platform and the speed of the currents. The effect is higher for a slim platform with the long side perpendicular to the flow of water. The magnitude of the impact corresponds to the amount of particles filtered from the water per volume of water, discussed above, the filtration rate of the organisms, the rate of flow, and the sediment content of the water. A slower flow increases the residence time of the water under the platform, increasing the number of particles that can be filtered from the water per volume. The filtration of the water will cease with the removal of the platform.

Impact assessment

The objective for floating infrastructure is to have a positive influence on ecosystem resilience, which might be enhanced through additional substrate attractive for filter feeders. More information about is described in Chapter 11. The extent is expected to be *medium*, the water flow is slower in lagoon areas than in the open ocean, but also not stagnant, and so water can pass under the structures. Because of this, the sedimentation will probably not occur highly concentrated in one area but will be more distributed, which makes the magnitude also *medium*. Duration will be *long* (as long as the structures are present), and the probability of filter feeders colonizing and reducing nutrients is *high* (Table 8.5).

Table 8.5: Impact assessment of water filtration by filter feeders and macrophytes

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

8.4. Bio-deposition by filter feeders

The filtration of the water by filter feeders leads to the accumulation of bio-deposits in the vicinity of the platforms. Organic enrichment and a high sedimentation rate through the accumulation of bio-deposits under floating platforms can lead to a change in the benthic community structure. The change in the distribution and abundance of filter feeding species may result in substantial changes in the biomass of phytoplankton and larvae (Connell, 2001). Depending on the local ecosystem, this can be either an opportunity or a threat.

Impact assessment

Bio-deposition will mainly cause a problem in areas where there is little water movement, in a closed off areas, shallow waters, and a dense ecosystem on the seafloor. The locations being considered for floating infrastructure in French Polynesia are generally deep, relatively open bodies of water, with significant flow rates. The extent will be *medium*; whereas, the bio-deposition will not only accumulate underneath the platform. The magnitude will be *low* because of the depth and water flow underneath the platform. The duration will be as *long* as the structures are present. The probability of bio-deposits occurring is *high* (Table 8.6).

Table 8.6: Impact assessment of bio-deposition by filter feeders

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

8.5. Design recommendations

A sewage treatment system, floating or on land, should be included in the design of floating infrastructure. In addition, a buffering system should be in place in case of malfunctioning. Water within the project should be reused as much as possible. Using rainwater, separating grey water, and black water, etc..

The growth of filter feeders and other species underneath the structures should be encouraged.

8.6. Monitoring recommendations

Nitrate and ammonia levels, as well as phosphates, should be monitored periodically.

9. Seawater alkalinity (pH)

Seawater total alkalinity (TA) measures the ability of seawater to neutralize acidity (hydrogen ions). The objective for floating infrastructure in French Polynesia is to have no significant influence on the seawater alkalinity of the SeaZone.

In the case of the floating infrastructure, pH can be influenced by the materials used for the platforms and human waste. The focus during the different phases of the development of the floating structures should be on waste management during the construction phase (no substances or waste should be dumped in the water), on the material used for the floating structures and moorings, and on the activities taking place on the structures.

Ecosystem vulnerability to changes in pH

The pH of seawater is dependent on the relation among the concentration of aqueous carbon dioxide (CO_2), bicarbonate (HCO_3^-) and carbonate ions (CO_3^{2-}). When more CO_2 dissolves in seawater the it becomes more acidic (ocean acidification). The majority of aquatic creatures prefer a pH range of 6.5-9.0. In the aquatic environments of French Polynesia, which are dominated by reefs and lagoons, pH levels are on the higher end of this spectrum: between 7.5-9.0 (Frei, 2008).

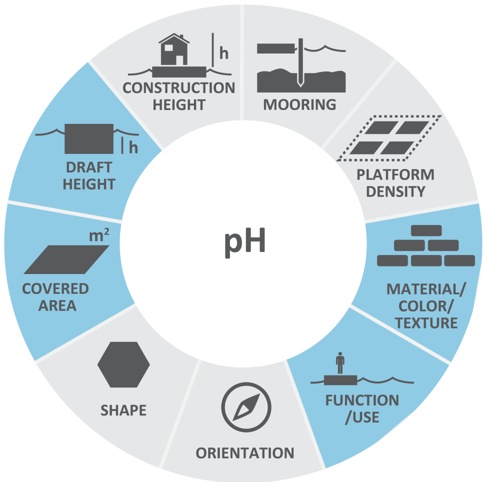

Figure 9.1: Project characteristics possibly affecting pH (in blue)

The most important factors that can affect pH are:

- Carbon dioxide (when CO_2 increases, the pH level decreases)
- Temperature (when temperature increases, the pH level decreases)
- Wastewater emissions, organic waste that enters the environment, runoff water carrying detergents (disposal increases pH levels)
- Acidic rain (decreases pH levels)
- Dissolved minerals (increase pH levels)(Utah State University Extension, 2017)

Carbonate materials and limestone are two elements that can buffer pH changes in water. Calcium carbonate ($CaCO_3$) and other bicarbonates can combine with either hydrogen or hydroxyl ions to neutralize pH. When carbonate minerals are present in the soil, the buffering capacity (alkalinity) of water is increased, keeping the pH of water close to neutral even when acids or bases are added.

If the pH level is higher or lower than the normal range, aquatic organisms might suffer from it. For example, lower pH levels (acidification) in marine environments can have pronounced effects on fish, making them more susceptible to fungal infections and other physical damage. In addition, acidification reduces the solubility of calcium carbonate, inhibiting skeleton and shell growth in calcifying organisms like corals. pH can also affect the solubility of nutrients in a positive way, however, making some more accessible to plants.[10]

Additional carbonate will especially be of value when the existing concentration in the water is low and calcifying organisms are present that require this for their growth.

Photosynthesis, respiration and decomposition affect pH levels due to their influences on CO_2. The uptake of CO_2 by plants, for example seagrasses, can locally increase the availability of carbonate ions (Manzello et al., 2012).

The following potential opportunity has been defined in terms of change in pH levels:

1. Concrete carbonation

This aspect will be evaluated in the following sections.

9.1. Concrete carbonation

The presence of concrete structures might affect the local pH. The extent of this effect is related to platform area, draft, and material. In seawater, concrete is affected by physicochemical corrosion due to wave movements and chemical reactions with molecules such as carbon dioxide, chloride and sulfate compounds. Elevated CO_2 levels not only increases concrete corrosion, but also reduces the concentration of carbonate ions, which corals and shell organisms use to build their structures (Feely, 2004). Concrete leaching could potentially 'balance' these negative effects, increasing the pH of seawater and providing a source of carbonate ions for corals and shell organisms growth, however this effect would most probably be on a very small, local scale.

Impact assessment

The leaching of carbonate from floating platforms will have to be analyzed to find out if it could be high enough to have a significant influence on the carbonate content of the lagoon water. In theory, concrete carbonation (leaching) could elevate pH levels, but compared to the levels of calcium in the marine environment this effect may not be significant. The extent is related to the submerged area of concrete and the magnitude is related to the water flow, depth, and how much concrete is released. Because of the very large water body this effect occurs in, extent will be *small* and magnitude will be *low*. The duration will be during the whole lifespan of the concrete,

[10] http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/

although the leachates will decrease. If the concrete is not covered with another material, the probability that it will leak is *high* (Table 9.1).

Table 9.1: Impact assessment of concrete carbonation

Spatial extent		Magnitude		Duration		Probability/frequency	
	Large		High	■	Long	■	High
	Medium		Medium		Medium		Medium
■	Small	■	Low		Short		Low

9.2. Design recommendations

The presence of plants (the uptake of CO_2) has a positive influence on the carbonate ions for calcification and should therefore be applied on and around the floating developments. Growing submerged foods like seaweeds, can have a positive impact.

9.3. Monitoring recommendations

The effects of concrete leaching can be monitored to evaluate if ecosystems are harmed or indeed might benefit from this phenomenon. **In either case, the effects are likely to be insignificant.** Ocean acidification (OA) is a worldwide challenge, and research and development of new methods and strategies on mitigation is of global importance. It is unlikely the floating infrastructure will have any net impact on OA, but the platforms will enable access to the marine environment enabling research on how OA is affecting coral reefs, as well as testing of potential solutions for local adaptation to any negative impacts OA might be causing.

10. Toxic substances

The objective for floating infrastructure in French Polynesia is to have no significant influence on the average amount of toxic substances within the SeaZone, or in the case of existing polluted areas, to reduce the average content of toxic substances and heavy metals to safe thresholds for local organisms.

Toxic materials can be present in different construction elements or equipment used during the construction phase and the operational phase. Toxic substances could be discharged during the use of floating infrastructure. The use of heavy metals in the floating platforms should be avoided as much as possible. If present, it should not be allowed to enter into the aquatic environment by means of urban runoff for example. Other sources of heavy metals are municipal wastewater and industrial wastewaters, particularly from the electroplating, electronic and metal-finishing industries (Gautam et al., 2014). If any of these activities are to take place on the floating platforms, additional precautions must be implemented. Special attention is also needed in the case of fish farming. The use of toxic substances for cleaning or maintenance should be limited and the users should be aware that it is prohibited to discharge these into the ocean water.

Ecosystem vulnerability to toxic substances

Increasing natural concentration of heavy metals is generally considered toxic for marine organisms. The term has particular application to cadmium, mercury, lead, and arsenic. Another potentially toxic metal is zinc, which is used to coat steel against corrosion. Copper is also on the list of toxic materials and is used for boating propellers, domestic wiring, and photovoltaic cells (Bell, 2016). Heavy metals are particularly dangerous in large concentration when particles enter plant or animal (including human) tissue via inhalation, diet, and direct contact. Other examples of toxic substances from domestic use include: turpentine, acetone (nail polish), mineral oils, emissions from antifouling paints, medicinal products (for human use, livestock, aquaculture and fish farms), pesticides and parasiticides (also fish farming), etc. (Canadian Centre for Occupational Health & Safety, 2017).

Figure 10.1: Project characteristics potentially affecting toxic substances/heavy metals (in blue)

Some chemicals and substances can have toxic effects (ecotoxicity), even when present in extremely small amounts, such as certain heavy metals (e.g. cadmium, copper, zinc), or pesticides. They can be accumulated by organisms up the food web and thus have an effect on vast areas that can persist in the environment for long periods (e.g., artificially synthesized compounds). Floating infrastructure introduces new materials into the environment. Depending on the materials used, leaching into the water may take place. The impact will depend on the nature of the substances involved. As long as these are not harmful for the environment (or organisms (ecotoxicity) this can be acceptable.

The following threats and opportunities potentially affecting toxic substances have been identified:

1. Leaching from concrete platforms
2. Leaching from treated steel components
3. Leaching from plastic or composite platforms
4. Leaching from wooden decks

These aspects will be evaluated in the following sections.

10.1. Leaching from concrete platforms

Concrete is a material that is often used for floating platforms. Concrete structures are often exposed to water right after casting, since it is beneficial for the curing process. According to Law et al. (2013), construction in water can release ions such as aluminum, calcium, magnesium, chromium, zinc, sodium and potassium, which among other effects, can raise the pH of surrounding water. In contained water bodies with poor water circulation, best management practices require that concrete curing is performed before placing the structures in contact with the water body. In marine environments, the release of such ions is more rapidly diffused and diluted and is less likely to have an ecological impact (Webster and Loehr, 1996).

Impact assessment

For the projects in French Polynesia, if concrete is chosen as a construction material, the curing process would most likely happen on land not in the water. Alternatively, concrete construction could take place on a floating dock, where excess production water can be collected relatively easily. Concrete contains trace elements that occur naturally in the minerals used for cement and aggregate. Trace elements that might be released during the operational phase are evaluated, based on ECN – Energie Onderzoekcentrum Nederland (Van der Sloot, 2011). The maximum levels of potentially harmful trace materials released during the life-time of the project (12 platforms) are projected to be <0.1 g (per 100y) for Hg, Tl, Be and <4 g (per 100y) for Pb, As and Cd.

The extent of this effect relates to the area of concrete that is submerged. The moving water can distribute the materials so the extent can be *medium* to *high*, the magnitude will be *low*, as the peak happens during curing and the toxins released afterwards are in very small quantities. Both duration and frequency will be *high*, as the concrete will leach all the time as long as its lifespan (Table 10.1).

Table 10.1: Impact assessment of leaching from concrete platforms

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

10.2. Leaching from treated steel components

Although steel is often the material of choice in shipbuilding, it is much less convenient for floating infrastructure. Steel requires intensive corrosion control measures, such as cleaning, painting and applying cathodic protection. Maintenance of steel structures requires temporarily relocation to a dry-dock. This is both expensive and time-consuming. In order to reduce the costs of cleaning and painting, 'anti-fouling' paints and 'corrosion control' measures are often applied, releasing potentially harmful substances into the environment. High concentrations of these substances in aquatic environments can cause abnormal development of organisms, affecting respiration, productivity, feeding and growth rates, or even lethal gill damage (Lewis and Cave, 1982; dos Santos et al., 2012). Studies have shown that such chemical compounds can persist in the environment, contaminating water, sediment and soil but also harming non-target species and entering the food web (Bighiu et al., 2017). The collection and disposal of biofouling material and paint waste is also a concern, since biofouling waste contains a high concentration of copper and zinc.

Impact assessment

The use of steel for the structures in French Polynesia will be limited. Because of negative environmental impacts of steel treatments (paints and anti-corrosion measures), steel will not be the material of choice for the floating platforms. The platforms will be made of concrete or HDPE (high-density polyethylene) and steel will only be used in minor components, such as mooring lines, connections, or small vessels.

Considering that only minor components are to be constructed from (treated) steel, the extent, magnitude and probability of leaching is considered *low* (Table 10.2). Steel vessels may contribute to leaching, but this is no different from existing coastal areas where vessels are allowed, although the effect of any increased quantity of these in the SeaZone should be evaluated.

Table 10.2: Impact assessment of leaching from treated steel components

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

10.3. Leaching from plastic or composite platforms

Many boats or yachts are made of polyester or epoxy resin (in combination with glass or carbon fibers). Emission risks during degradation or at high temperatures exist, but are very limited for most plastics (PE, HDPE, PP, and Epoxy). Black HDPE[11] has been mentioned by boat producing companies as a favorite material and could be an interesting option. If these plastics need to be treated (for UV protection or other reasons), treatment materials also need to be examined for toxicity. Endocrine-disrupting compounds (EDC) in PVC, Polyester resin and Polyurethane (PU) have a higher probability of leaching toxic substances and should not be used, or not be in contact with the water or rainwater runoff.

Table 10.3: Impact assessment of leaching from plastic or composite platforms

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

10.4. Leaching from wooden decks

Wood is a preferred material for marine applications, but dense and highly moisture resistant varieties are often pricey and scarce. For wood types that are less costly and more widely available, treatment is required to protect against corrosion and decay. Pressure treatment with either water-borne or oil-based preservatives is usually applied, but many of these products can be harmful to the environment.

Copper Chromated Arsenate (CCA) is a waterborne preservative used extensively worldwide owing to its wide range of effects on target organisms (bacteria, fungi, marine borers, etc.). However, individual elements of CCA have been found toxic to non-target organisms (Tarakanadha et al., 2004). An alternative waterborne

[11] http://tidemanboats.com/hdpe-the-new-plastic-10-reasons-to-choose-a-hdpe-workboat/

preservative is Alkaline Copper Quat (ACQ). Despite the fact that ACQ does not contain harmful substances such as arsenic and chromium, significant effects on non-target organisms have been reported. Tarakanadha et al. (2004) indicated that higher risks could be found associated with alternative preservative treated wood products, which have higher levels of copper content when used in aquatic environment. In fact, studies conducted in the 1990s, both in the laboratory and natural environments, demonstrated that Copper (Cu) leaches the most. In addition, copper is the most toxic element to marine organisms among the three metals (Copper, Chromium and Arsenic) leached out from the wood treated with preservatives. Accumulation in nearby sediments and biota were severe in areas that were not well flushed by tidal action (Weis, J. and Weis, 2004). Therefore, the use of alternative preservatives is not recommended in sensitive aquatic environment in areas characterized by limited flushing.

In oil-based preservatives such as creosote, oil forms a barrier to salt intrusion, leading to less damage from salt in wood treated with such preservative. Despite the efficiency in preserving wood from salt, creosote is reported to have a certain degree of toxicity to marine organisms (Marwood, 2003).

Many types of tropical timber, such as merbau (kwila), teak or ipé, have natural resistance to moisture, fungi and insects. In addition, oil-based marine coatings are available that prevent moisture intrusion. They are traditionally used to paint the decks of boats and are based on natural oils (tung, or linseed) that do not appear to impact the environment.

Impact assessment

For the floating infrastructure project, the objective is not to apply harmful wood treatment products, or to do so only in areas where it will not have contact with the lagoon nor be used where runoff water is collected and treated. Availability of moisture-resistant wood in French Polynesia will be investigated, or alternative protection measures that are not harmful to the environment will be applied. Therefore, spatial extent will be *medium* due to the currents, duration should be *long* as the platform life. Both magnitude and probability have been rated '*low*' (Table 10.4).

Table 10.4: Impact assessment of leaching from wooden decks

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

10.5. Design recommendations

If the right materials are used, the emissions of chemicals into the marine environment should be minimal. Nontoxic materials should be preferred. Several sources are available online to help designers identifying health hazards of materials, products and chemicals that are used in the built environment. A list of useful information and links is included in the LBC Materials Petal Database, available at: https://goo.gl/Ak7EKd.

A critical aspect could be the construction phase, where it is more likely for waste materials to accidentally reach the ocean. Rain wash-off chemicals from building surfaces should not be directly discharged in water, but collected and treated to avoid pollution. Good planning of the building process could minimize such accidents. During the operational phase of building, painting, staining, scraping or other maintenance to structures could introduce contaminants into the ocean. Attention should be given to the choice of non-toxic materials and to avoid the discharge into the environment during building maintenance.

Finally, if floating platforms are to be connected to infrastructures on land, care should be taken to avoid leaks from pipes (e.g., gas or oil).

10.6. Monitoring recommendations

Monitoring needs to take place during construction and operation to measure any inputs to the environment and determine the consequences.

11. Community structure and species abundance and diversity

The objective for floating infrastructure in French Polynesia is to maintain, or in the case of an already degraded ecosystem, to restore the balance between different species that are present in the SeaZone.

Introduction of floating structure to the environment will provide a new structural habitat that in some cases might have the potential to increase species richness or it could have a negative impact. Materials like concrete, granite and steel are claimed to contribute in some circumstances to successful coral restoration (see reference from Seaman, 2000; Precht, 2006).

Ecosystem vulnerability

Ecosystems are structured in a food web that can be divided into a number of trophic levels. Figure 11.1 illustrates a marine food web, with at the base the primary producers like sea-grass and corals followed by herbivorous consumers and various levels of predators towards the top of the pyramid.

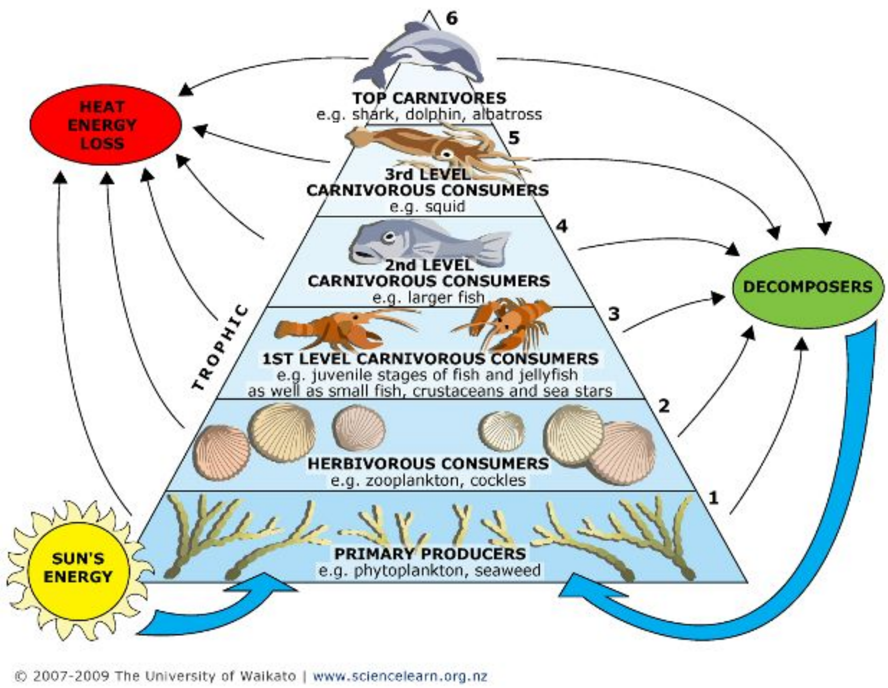

Figure 11.1: Marine trophic level (Science Learning Hub, 2012)

According to researchers in French Polynesia (expert interviews), there are two important ratios that generally indicate a healthy coral reef ecosystem: (1) the ratio between corals and algae and (2) the ratio between herbivores and carnivores.

Floating infrastructure can influence community ecology and the behavior of organisms. The direct influence stems from the introduction of a new hard substrate, which potentially leads to the colonization of the new habitat by sessile species that may provide a foundation for mobile species. This provides additional space to local species, but may also attract species that are new to the location.

Introducing new habitats that are unique to an environment can promote species dispersal and increase biodiversity, but it may also change the local community structure. In terms of species composition, floating platforms are likely to promote sessile filter feeders underneath (e.g., bivalves, sponges, non-zooxanthellate coral), and photosynthetic species on the sides (e.g., zooxanthellate corals, various types of macroalgae).

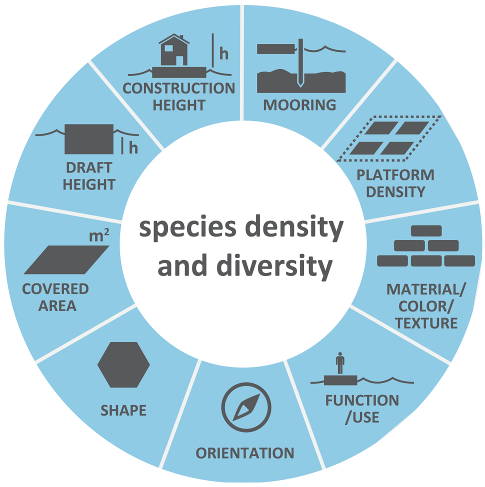

Figure 11.2: Project characteristics possibly affecting species density and diversity (in blue)

The following threats and opportunities potentially affecting community structure have been identified:

1. Floating platforms as artificial reefs
2. Colonization of platforms by sessile organisms
3. Colonization of platforms by mobile organisms

These aspects will be evaluated in the following sections.

11.1. Floating platforms as artificial reefs

The potential for floating platforms to act as an artificial reef, depends on the ability of coral recruits to reach and settle on the platform surface. This is influenced by the behavior of local coral recruits, the distance to natural reefs, the material used for the platform, water movement, and the habitat quality of the platform location.

The artificial reef might benefit the ecosystem if it can become a (future) source of coral recruits for adjacent natural reefs and a nursery for marine species. This could help support the recovery of natural reefs after degradation events (such as mass coral bleaching events). The resilience of coral reefs depends on their capacity to recover from disturbances (Mumby and Harborne, 2010). Slow, chronic drivers of change, such as fishing pressure, added nutrients, rising temperatures and ocean acidification, reduce the ability of coral reefs to recover from acute disturbances like cyclones (Hughes et al., 2010). After acute disturbances, successful recruitment is essential for the recovery of coral reef ecosystems (Tamelander, 2002). It is possible that floating structures might offer some protection from these threats and act as source of recruits for disturbed reefs, supporting their recovery. At the same time, floating structures might reduce the impact of chronic disturbances for neighboring reefs through shading, water filtration by filter feeders, induced sedimentation near platforms.

While not doing any harm, the positive contribution of floating infrastructure to coral reef resilience might be minimal, but efforts can be made to provide at least some positive (regenerative) effect.

Introduced floating structures interact with the aquatic environment and create a novel habitat that has no equivalent in nature (Connell, 2000). Fixed, artificial structures such as **piles** often provide a habitat for diverse coral communities. Chou and Lim (1986) studied coral communities in Singapore. Comparing the ones on concrete pillars with communities in natural areas nearby, they found greater species diversity and coral cover on concrete structures (vertical jetty concrete piles had double the coverage and species compared to the nearby natural reef slope). In another area of Singapore, corals were found to be prevalent on concrete and granite structures, particularly in shallow sections (Tan et al., 2012). In Eilat (Red Sea), coral diversity and cover in submerged metal and PVC nets were found to be comparable to or higher than that of nearby natural habitats (Perkol-Finkel and Benayahu, 2004).

The **material** texture seems to have a certain influence on the density of sessile organisms. Pomerat and Weiss (1946) tested a wide range of materials and their influence on the attachment of marine organisms and concluded that porous or fibrous surfaces are more effective as fouling collectors. Research by Brown (2005) on artificial reefs concluded that, in the long run, the choice of the construction material for artificial reefs will have low influence on the epifaunal community structure, "*as long as the material is physically stable, non-toxic and offers a high degree of habitat complexity*". Other sources point out that the influence of surface structure on assemblages might vary according to the organisms. Coral larvae for example are more likely to settle with feature sizes that closely match their own dimensions, whereas some sponges do not have specific requirements (Whalan et al., 2015). The presence of biofilm is also preferred by some species, but not necessarily by others (Crisp and Ryland, 1960).

Some studies concluded that **color and orientation** of surface have a certain influence on the types of species attached to it (Bighiu et al., 2017; Satheesh and Wesley, 2010). Experiments by Bighiu et al. (2017) on plastic panels of different colors in the Northern part of Baltic Sea showed that barnacles and mussels set more abundantly on dark surfaces (blue, black and red). Mussels were found mostly on panels facing north-east, whereas algae were more present on panels oriented south-east.

Impact assessment

The extent of this impact refers to the size of the underwater area of the structures and for the ecosystem around it; therefore, the extent will be relatively *small*. The increase in species diversity and density relates to the magnitude. In the case of the floating reef, this will be limited to the size of the platforms. The opportunity for artificial reefs to support natural reefs during natural disturbances (e.g. bleaching events) may have a larger spatial extent. In order for this to work, the ideal location would be nearby natural reefs, but not directly in contact with them (to prevent direct competition). The probability that an artificial reef will attract sessile and mobile species is *high*, but this secondary effect will be treated separately in the next paragraphs (Table 11.1).

Table 11.1: Impact assessment of floating platforms as artificial reefs

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

11.2. Colonization of platforms by sessile organisms

Floating platforms introduce new hard surfaces, which are very likely to be colonized by sessile marine organisms. Species that are usually found on floating structures include bivalves, sponges, ascidians, bryozoans, and foliose algae, which benefit from the higher mass-transfer rate and current velocity near the water surface (Perkol-Finkel et al., 2006). Research indicates that pilings and pontoons can provide new habitats for marine species and may act as a stepping stone for the dispersal of sessile (immobile) organisms; at the same time pontoons demonstrated to give rise to more distinct assemblages of sessile biota, compared to pilings and natural reefs that do not move along with the water level (Connell, 2001).

Because of the hard substrate offered by floating platforms, in combination with lower light levels directly under the platform, sessile filter feeders such as bivalves are likely to become one of the dominant species. Environmental advocates have pursued bivalve restoration (in particular oyster) to re-establish historical baseline conditions and functioning of estuaries, because of the many services they offer to the ecosystem:

1) improving water quality and counter-acting eutrophication by buffering excess nutrients and creating bio-deposits;
2) reducing turbidity and thereby supporting photosynthetic organisms
3) providing a structural habitat to epibiota, fish and crustaceans, potentially contributing to habitat heterogeneity;
4) Regulating planktonic bacteria and fungi;

(Herman et al., 1990; Dame and Olenin, 2005; Lotze et al., 2006; Coen et al., 2007).

The presence of man-made floating structures, such as pontoons, buoys, etc., often can lead to unique and diverse species assemblages of sessile organisms (Perkol-Finkel et al., 2008). Reasons for this diversity might be due to the isolation of floating structures from the sea floor and because their subtidal surfaces are continuously exposed to surface swash. In addition, since floating structures are located on the water surface, subtidal habitats in such structures experience greater and more constant light intensity compared to fixed habitats (Holloway and Connell, 2002).

Impact assessment

There is a *high* probability that the community structure directly near the project will change due to colonization of sessile organisms. The effects are likely to be positive: promoting species richness and providing additional services to the ecosystem. These changes will be permanent to the location, unless the project is relocated or removed.

Table 11.2: Impact assessment of colonization of platforms by sessile organisms

Spatial extent		Magnitude		Duration		Probability/frequency	
	Large		High	■	Long	■	High
	Medium		Medium		Medium		Medium
■	Small	■	Low		Short		Low

11.3. Colonization of platforms by mobile organisms

The presence of floating structures might attract different types of fish. For example, the number of fish reportedly increases near offshore oil platforms that have more 'biofouling' (Rooker et al., 1997). In Sydney harbor, Clynick et al. (2007) observed that the abundance and diversity of fish were associated with the amount of sessile organisms that were available on pilings, such as foliose algae, ascidians and mussels. Epibiota provide food and shelter for small fish (Clynick et al., 2007; Moreau et al., 2008). Additionally, the shade produced by floating structures may attract fish since shade provides a visual advantage, reducing both background light and veiling brightness[12] (Helfman, 1981). Moreover, reef fish have also been found to hide under tabular structure, not only because of protection against predators, but mainly because of protection against UV-B irradiance (Kerry and Bellwood, 2015).

An important question is whether or not fish might be attracted from the surrounding environment and aggregate at the artificial reef, to the detriment of surrounding areas, or if the artificial reef supports the reproduction of reef fish and leads to an increase in the local population across the entire zone. Studies supporting either hypothesis exist, and both attraction and production appear to be potential effects of artificial reefs.

[12] Veiling brightness refers to a phenomenon that happens to the eye underwater. The suspended particles close to the eye reflect the light and create a bright region near the observer. This bright area makes it more difficult to see distant targets. When a fish swims under a floating platform, sunlight is shaded and the veiling brightness reduced. Since the area near the fish eye is now less bright, the fish can see further and spot predators more easily. (Helfman et al., 2009)

Artificial reefs might provide food, shelter, physical orientation, and recruitment habitat for settling individuals, which would be lost to the population without the existence of the artificial reef.

When organisms on a natural reef are limited by the availability of habitat, and by increasing suitable habitat, an artificial reef might increase production. On the other hand, if individuals settle on the artificial reef, which otherwise would have settled on a natural reef of higher habitat quality, the artificial reef can lead to a reduction in the total abundance of the species. When overfishing occurs in the environment, the aggregation of scattered fish can be a risk. By facilitating the capture of fish, the artificial reefs become an ecological trap. An artificial reef can also reduce the human use pressure for the surrounding natural reefs (Broughton, 2012). The structure of artificial reefs influences the abundance and diversity of species living in the reef. Generally, higher structural complexity of the artificial reef increases the abundance and diversity of species (Broughton, 2012). Small crevices provide refuge from fish predation for coral spats (Nozawa, 2012; Suzuki et al., 2011).

Impact assessment

The extent of the impact relates to the size of the underwater structures where colonization can take place. The benefit will mainly apply near the structures, which results in a spatial extent that is rated '*small*'. The magnitude relates to the increase of the species diversity and density, which are both expected to increase significantly, and for the mobile organisms, this will not be limited only to vicinity of the platform. The probability is *high*, because the structures will be designed and adjusted to serve this purpose. The duration will last as *long* as the structures are present (Table 11.3).

Table 11.3: Impact assessment of colonization of platforms by mobile organisms

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

11.4. Design and operation recommendations

Platforms structures and materials could be designed taking into account the possibility of organisms to attach to them. Porous or fibrous surfaces are more effective as fouling collectors on the attachment of marine organisms. Concrete is a very popular material for coral species, but also granite, steel and plastics provide opportunities for corals to settle. Overall, it is most important that the material is physically stable and non-toxic. Research on plastic panels of different colors showed that barnacles and mussels settling is more abundant on dark surfaces (blue, black and red).

11.5. Monitoring requirements

Considering that species composition and community structure is likely to change, it is important to monitor the developments, at least up to the point that the local ecosystem has stabilized. The results are like to be beneficial to the ecosystem, but this has to be confirmed by studying the development of the community structure. Additional topics that are interesting to monitor is whether platforms acting as an artificial reef have a positive effect on natural reefs, supporting them during natural hazards or disturbances.

12. Animal behavior

The objective for floating infrastructure in French Polynesia is to either have no significant influence on animal behavior, or to influence animal behavior in a way that increases the resilience of ecosystems.

During the construction phase, drilling works (if mooring poles are used) could cause severe noise disturbance that must be mitigated to minimize disturbance of wildlife. The presence of the floating structures can obstruct the flow of certain floating species, and the presence of such species needs to be considered and the shape, size, depth, orientation, and development density adjusted accordingly. During the use of floating infrastructure, machinery, engines, and other activities that produce significant noise should be isolated to avoid nuisance or damage to the ecosystem. Favoring the use of silent transportation systems (notably electric power) might also reduce spills of toxic substances.

Ecosystem vulnerability to changes in animal behavior

Animals move for a variety of reasons, to forage or hunt for food, find a mate and breed, escape predators or locate a more suitable microhabitat. Many animals must change habitat to complete different stages of their lifecycle.

Forcing behavioral changes can influence the fitness of organisms and lead to ecological impacts. Monitoring animal behavior to identify and mitigate changes resulting from human activity can help maintain ecological integrity.

The following threats and opportunities potentially affecting animal behavior have been identified:

1. Obstruction of species movement
2. Noise pollution
3. Wildlife-vessel collisions
4. Artificial light

These aspects will be evaluated in the following sections. (Point 4 was considered earlier).

12.1. Obstruction of species movement

The presence of floating structures could influence the movement of some species. Most fish have little trouble using culverts (closed fish passages), as long as flow velocity and culvert length are limited (<30m) (Gregory et al., 2004; Kemp et al., 2006; Vowles et al., 2014; Welton et al., 2002). A limited number of obligate floating (pleustonic) species that may be encountered in French Polynesia, including types of polyps (e.g., blue-bottle, portuguese-man-of-war), pelagic nudibranchs (Glaucidae), and marine algae cannot swim on their own. Many of these are dependent on currents and wind to move around. Poorly designed floating structures could introduce pockets of water flow stagnation that accumulate floating materials and organisms. This is usually highly dependent on constantly changing factors: direction and intensity of currents, winds, waves. It is not likely to be a permanent effect but it could have a persistent impact during certain times of year and particular conditions. The design phase must take this into account.

Impact assessment

To measure the extent of this impact, an assessment must identify how many potentially affected species are present at the specific location. Furthermore, the total area of the floating structures needs to be considered, the depth and the shape. The magnitude of the impact is defined as the number of routes that are blocked per square meter of floating platform, which depends on the shape, orientation, and number of individual platforms. If a dominant direction of movement exists, the number of routes blocked will be lower for a slim platform with the long side parallel to the dominant movement direction. If the movement is multidirectional, the magnitude of impact will be lower for a compact platform. A few smaller platforms are likely to have lower impact than one large one. The vulnerability of an ecosystem to the disruption of species movement patterns by floating platforms depends on the characteristics (density and frequency) of those patterns and the dispersal capacities of the species present. Any disturbance would presumably cease with the removal of the platform, although some species might take a long time to return to previous patterns. The extent of any impact is limited by the area of the structures in the water, which for the current project will be *small*. The magnitude is hard to predict without a detailed assessment on the biological community at the site. The duration will be as *long* as the platforms are present and perhaps longer, the probability that is would block will be *medium* or *small*, assuming the design is adjusted to reduce any high probability impacts (Table 12.1).

Table 12.1: Impact assessment of obstruction of species movement

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

12.2. Noise pollution

Ecosystems, including marine ecosystems, are sensitive to many sounds resulting from human activities. Sound is used for communication between a wide range of aquatic and semi-aquatic animals. The presence of anthropogenic sounds can alter the ability of organisms to gain an overall acoustic image of their environment, making them more susceptible to environmental threats (AEI, 2008; Gisiner, 1998). According to the World Health Organization, anthropogenic noise is one of the most hazardous forms of pollution and has become omnipresent within terrestrial and aquatic ecosystems (Kunc et al., 2016). Intense and impulsive noise influences physical well-being and can lead to tissue damage, low intensity noise is more likely to influence behavior. Figure 12.1 shows how long term exposure to noise can harm fish.

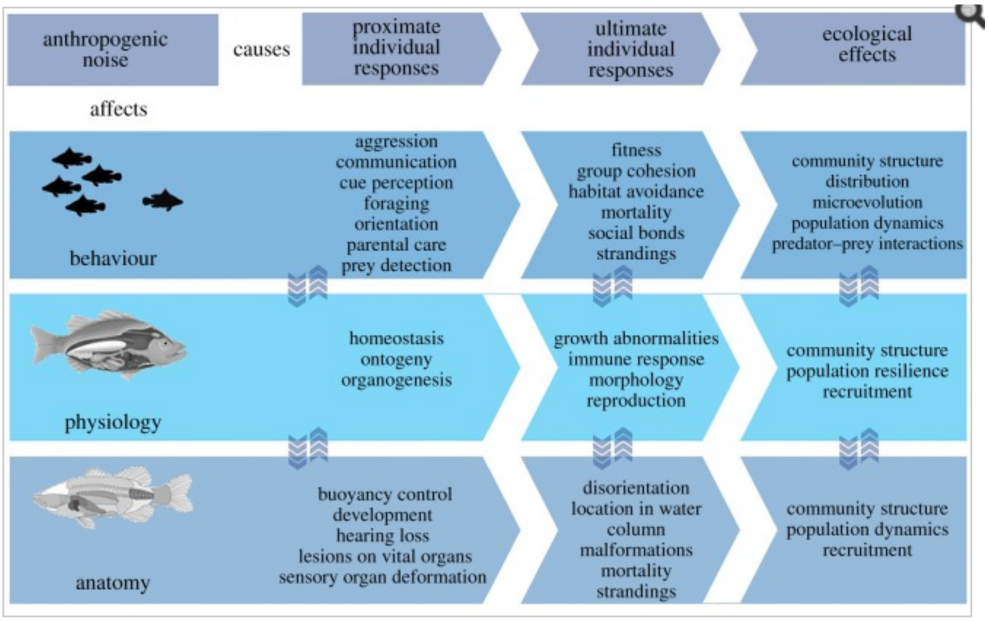

Figure 12.1: Observed damages on fish caused by antropogenic noise Source: Kunc et al.,(Kunc et al., 2016).

Coral reef systems, notably in French Polynesia, have been the subject of increasing scientific study highlighting the significance of sound in these ecosystems, and the potential impacts of sound pollution.

Impact assessment during construction

The extent of the impact depends on the source of the noise, the intensity and the duration. Strict rules for the construction phase will need to be in place to minimize impacts. Construction will take place on land and the installation of moorings is likely to be the most significant source of noise pollution affecting the site. In order to reduce mooring noise, various technologies are being investigated, including drilling, suction pile anchors, BLUE piling, and vibratory pile driving. Because noise travels far, it has a large extent; moreover, at close range, the high intensity noise also has a high magnitude in harming aquatic life. Duration is limited to the construction period (Table 12.2).

Table 12.2: Impact assessment of noise pollution during construction

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

Impact assessment during operation

A major source of noise might result from transportation from and to the floating structures. The goal is to use electrical engines as much as possible, however, the use of conventional fossil fuel motors with their loud engines will likely still occur.

Transportation will most often occur between the platforms and the land. The sound produced is not as loud as construction noise, and so the magnitude will likely be lower. The duration might be *short* for each journey but the frequency could be *high*, as movements from and to the platforms will be persistent (Table 12.3).

Table 12.3: Impact assessment of noise pollution during operation

Spatial extent	Magnitude	Duration	Probability/frequency
Large	High	Long	High
Medium	Medium	Medium	Medium
Small	Low	Short	Low

12.3. Wildlife-vessel collisions

Collisions of wildlife with vessels do occur and the movement of the water and noise can disturb some species. Avoiding vessels is possible for many marine species, but others, like corals, are sessile and cannot avoid being hit (e.g., by boat propellers or anchors). Transport on water is generally more flexible than on land, but this is less true in coral reef lagoons where navigable channels can be very limited and there is a high risk of hitting coral heads. The extent of collision is *small*, only at the spot where the collision happened, this also accounts for the magnitude. The duration is incidentally and the probability/ frequency could be *low*, as precautions will be taken upfront to clearly mark the no-go areas (Table 12.4).

Table 12.4: Impact assessment of wildlife-vessel collisions

Spatial extent		Magnitude		Duration		Probability/frequency	
	Large		High		Long		High
	Medium		Medium		Medium		Medium
■	Small	■	Low	■	Short	■	Low

12.4. Design recommendations

Noise from floating infrastructure should be avoided as much as possible. During the construction phase, the installation of moorings can cause serious noise and disturbance. During operation, any activities that produce considerable noise should be limited, or take additional precautions (isolation mechanisms) to reduce noise. The use of bubble screens or clouds, were found to be a promising method to limit the speed and the intensity of sound underwater (King, 2016). Further research is required to evaluate the potential of such a system.

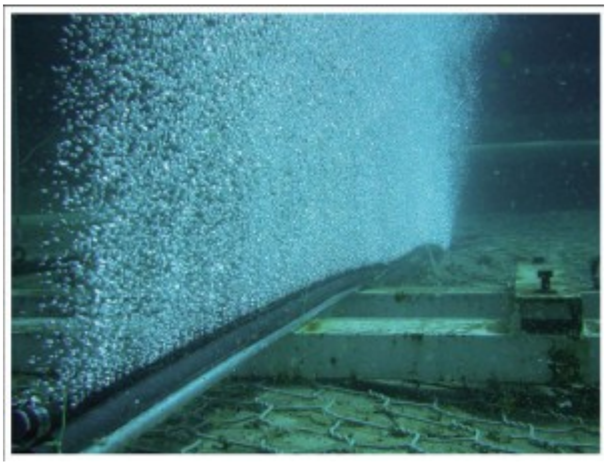

Figure 12.2: Example of bubble screen. Source: Canadianpond (2017)

Motorized vessels are expected to be one of the main sources of noise disturbance. Electric engines can reduce both exhaust and noise emissions and should be preferred. It is important to create awareness of this issue, and promote the development of adequate solutions that could minimize noise pollution. Quiet environments have a positive effect on the well-being of both wildlife and humans. It could be useful to connect the floating infrastructure by floating bridges, reduce maximum speed, and investigate electric air transportation alternatives, and to allow only non-motorized or electric boats.

Depending on the size and characteristics of the floating project, water-based transportation can be accomplished using personal or collective means (e.g., a water bus). The first is more adequate for a low-density development. Small paddleboats or outriggers can be used to commute (sometimes even for long distances) their impact is minimal. Bigger agglomerations would justify the use of group transportation.

Monitoring recommendations

Monitoring animal behavior can help identify and remove potential negative impacts before the change in behavior leads to a decrease in population size.

13. Conclusions & recommendations

All the aspects that have been discussed interact with multiple biological, chemical, and physical processes. Because many of these interactions occur simultaneously, are part of feedback loops, and are characterized by significant spatial and temporal heterogeneity, the assessment of how the environment will behave in the presence of floating infrastructure is highly complex and impossible to predict with certainty. The approach proposed is to simulate different scenarios and identify those that are most likely to maintain or increase ecological resilience. In some cases, there will remain significant risk and uncertainty. These cases should be recognized and appropriate monitoring and research put in place as part of an adaptive management strategy.

It is clear that floating structures will change the environment but the scale of the project is relatively small, which minimizes any negative impacts – and some negative impact is unavoidable despite the stringent efforts to foresee and avoid them. Risks to the entire lagoon basin are limited to construction and installation noise. The second most important risk is wastewater treatment, and especially malfunctions. Other impacts are likely to be *low* in magnitude or extent, and there are also likely to be some benefits for ecosystem health. Nevertheless, the exact outcome of the creation of a new and unique habitat for marine life remains difficult to predict. This first project is at a relatively small scale and will engage a significant research component precisely to improve our understanding of how floating infrastructure interacts with the environment. The lessons learned will be incorporated into the adaptive management plan for this project and will be invaluable for the design of future projects.

An overview of the findings, classified into threats and opportunities is presented below.

13.1. Potential threats

The most important issues that have been found in this study relate to the **operation phase**:

- Minimizing artificial light at night and imposing specific wavelengths
- Prevention of wastewater treatment malfunction
- Prevention of littering and noise pollution
- Promoting responsible boat traffic (in terms of sound, artificial light, emissions, minimizing collisions with coral, and other disturbances)

In the **design phase** it is crucial to plan for sufficient light to enter the water column to minimize impact of shading. This can be ensured by allowing sufficient space in between platforms, and to choose a location that has sufficient depth compared to the scale of the platform. Another design aspect that will mitigate impacts, is to choose materials that are thought to have no (or very limited) impact on the environment. It is also important to take proper measures to limit the impacts during operation phase. This includes a street lighting design, a water infrastructure design and measures to prevent litter and noise.

The **construction phase** should take place on land or on a floating dock in a location that is less vulnerable than a coral reef lagoon, where residues, packaging and leftover materials can be properly disposed of. Installation and mooring of the platforms will need to be done with great care.

13.2. Potential opportunities

Several opportunities have been identified in this study:

- Artificial floating structures can promote colonization by marine wildlife
- Colonization by sessile filter feeders may have a positive effect on sedimentation and water quality (specifically nutrient cycling).
- Floating platforms and related activities (such as Seawater Air Conditioning) could positively affect water temperature and alkalinity

In order to assess all aspects properly, more information is required on the exact location and the design. This document is intended to inform the choice of location and guide the detailed environmental impact study and broader scientific study of the long-term performance of the floating infrastructure. The goal is to develop design principles that will result in the most ecologically sensitive project.

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Appendix 1 - EIA Legislation in French Polynesia

New developments require screening to find out if it requires an Environmental Impact Statement or Assessment.

According to article LP 232-2 of the code, the environmental impact study should include:

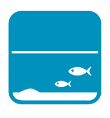
1. identification of the contracting authority;
2. a comprehensive description of the proposed action and any plans necessary for an understanding of the proposed project and the Environmental Impact Statement (EIS);
3. identification of the regulations relating to the environment applicable to the proposed action, stating in particular the presence of facilities classified for environmental protection and topics and thresholds concerned;
4. analysis of the initial state of the site and its environment, including on natural and cultural resources, natural areas, land or sea, scenery, water, any existing pollution;
5. an analysis of the environmental impacts of proposed actions on the media described in the preceding paragraph, especially on sites and landscapes, fauna and flora, natural environments and biological balances, aspects socio- Economic problems, neighborhood, public health and hygiene, water, air, pollution and potential nuisance produced;
6. reasons and justifications for the proposed project was selected, the point of view of environmental concerns relative to alternatives or alternative solutions;
7. a description of the measures provided by the project owner or the petitioner to suppress, prevent and compensate for the harmful effects on the environment and the corresponding expenditure estimates. An environmental impact monitoring program will be planned where appropriate;
8. a succinct and understandable summary of the impact assessment;
9. identification and the most accurate and complete as possible for individuals and legal entities, including associations, likely to be affected by the project identified in the impact study.

ENVIRONMENTAL IMPACT ASSESSMENT

1. Authority
identification of the **contracting authority**;

2. Proposed action
description of **proposed action and plans** necessary to understand proposed project and the Environmental Impact Statement;

3. Environmental regulations
identification of the **regulations** relating to the environment applicable to the proposed action, stating in particular the presence of facilities classified for environmental protection and thresholds concerned;



4. Baseline
analysis of the initial state of the site and its environment, including on natural and cultural resources, natural areas, land or sea, scenery, water, any existing pollution;

5. Environmental Impact
analysis of environmental impacts of proposed actions (landscape, fauna & flora, natural environments and biological balances, socio-economic influence, public health, water, air, pollution & nuisance)

6. Justification
reasons and justification for the proposed project compared to **alternatives**

7. Mitigation
measures to suppress, prevent and compensate for the harmful effects on the environment. A **monitoring program** is planned where appropriate;

8. Summary
A non-technical **summary** of the EIA;

9. Affected parties
complete/accurate account of **individuals and legal entities likely to be affected.**

Appendix 2 - Abbreviations

BACIPS	Before After Controlled Impact Pairs Series
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DIREN	Direction de l'Environnement [Environment Directorate]
EIA	Environmental Impact Assessment
EMMAs	Educational Managed Marine Areas
FIRST	Floating Infrastructure Research: Science and Technology
MABs	Man and the Biosphere Reserves
MARPOL	Marine Pollution
MBR	Membrane Bioreactor
MMA	Marine Managed Area
MOU	Memorandum of Understanding
OA	Ocean Acidification
PGEM	Plan de Gestion de l'Espace Maritime [Maritime Space Management Plan]
SEA	Strategic Environmental Assessment
SPREP	Secretariat of the Pacific Regional Environment Programme
SWAC	Seawater Air Conditioning
WWTP	Wastewater Treatment Plant
ZPRs	Regulated fishing zones

Appendix 3 - Terminology

The terminology used in the report is described in this section. For the purposes of this document, we assume that all seasteading developments take place within the **Exclusive Economic Zone** (**EEZ**) of a **Host Country**.

Adaptability: in ecology, adaptability is the ability of a system to cope with unexpected disturbances in the environment (Andresen and Gronau, 2005). In this report, adaptability refers to the ability of an ecosystem to adapt to unpredictable changes in the environment and preserve its ecological functions.

Benefit: a measure of the consequences and probability of a positive impact. Benefits arise from the interaction between opportunities and ecosystem adaptability.

Floating infrastructure: design, planning and construction of buildings, platforms, infrastructures and other structures on buoyant foundations moored to the bottom of a water body (e.g.: lake, river, sea). Contrary to most buildings and infrastructures on land, floating structures are generally more mobile. If required, floating buildings and platforms can be disconnected from their mooring system and transported to a different location. Since floating structures are directly placed on the water surface, they move up and down according to the water level. This unique property makes floating development interesting for communities that are threatened by sea level rise. Floating developments can consist of various functions such as residential, food production, energy generation, wastewater treatment, and many more. Moreover, they can create new shelter or habitat for flora and fauna. Floating developments also offer the opportunity to develop and test water-based innovations for energy production and waste treatment/reuse, supporting the progress in circular urban metabolism and the green-blue economy.

Threat: a threat has the potential to cause injury, loss of life, property damage, socio-economic disruption or environmental degradation. Threats can refer to climate-related natural events such as hurricanes and earthquakes or human-induced ones such as explosion of hazardous materials (The Geographer Online, 2015). In this report the term is referred to an event or action that has the potential to cause negative impacts on an ecosystem.

Impact: a negative or positive change as a result of an action, activity or event. It refers to the impact of a project on the environment, as well as the impact of the environment on a project due to an environmental hazard or environmental change process. Examples of negative impacts include environmental degradation, injury or loss of life, property or infrastructure damage and social unrest. Examples of positive impacts include environmental recovery and restoration, increased food security, property or infrastructure improvements and increased local job opportunities (SPREP, 2016).

Impact consequence: a combination of the impact intensity and the extent and duration of the hazard/opportunity.

Impact duration: the timeframe over which an impact will be experienced and its reversibility (SRK Consulting, 2014).

Impact extent: the area over which an impact will be experienced (SRK Consulting, 2014).

Impact intensity: a combination of the magnitude of the hazard/opportunity and the vulnerability/susceptibility of the ecosystem.

Impact significance: a combination of the impact consequence and the probability of the impact.

Magnitude: the strength of a hazard or benefit.

Opportunity: a set of circumstances (incidence/event) with potentials to bring renewal and positive effects to an ecosystem.

Polynesia Floating Infrastructure Research: Science and Technology (FIRST) Consortium: a collaboration between institutions with scientific facilities in French Polynesia and The Seasteading Institute (see Polynesia FIRST MOU).

Probability: the likelihood of occurrence of a certain impact.

Risk: a measure of the consequences and probability of a negative impact. Risks arise from the interaction between hazards and ecosystem vulnerability.

Seasteading: The practice of establishing permanent settlements on structures located in areas of sea outside the jurisdiction of any country.

SeaZone: an area of the marine environment under a special administrative structure as legislated by the Host Country. Within a SeaZone there can be one or more floating platforms, as determined by the local setting and legislation. When the SeaZone is deemed fully developed (built out), a new SeaZone could be established, as agreed with the Host Country.

Threat: an event or action that has the potential to cause significant negative impacts on an ecosystem.

Vulnerability: the sensitivity of a development, human community or ecosystem to damage and loss resulting from a hazardous event or disturbance (SPREP, 2016). The framework proposed in this report (Figure 3.1) focuses on the sensitivity of a given ecosystem.