HSE Guideline

D2.2

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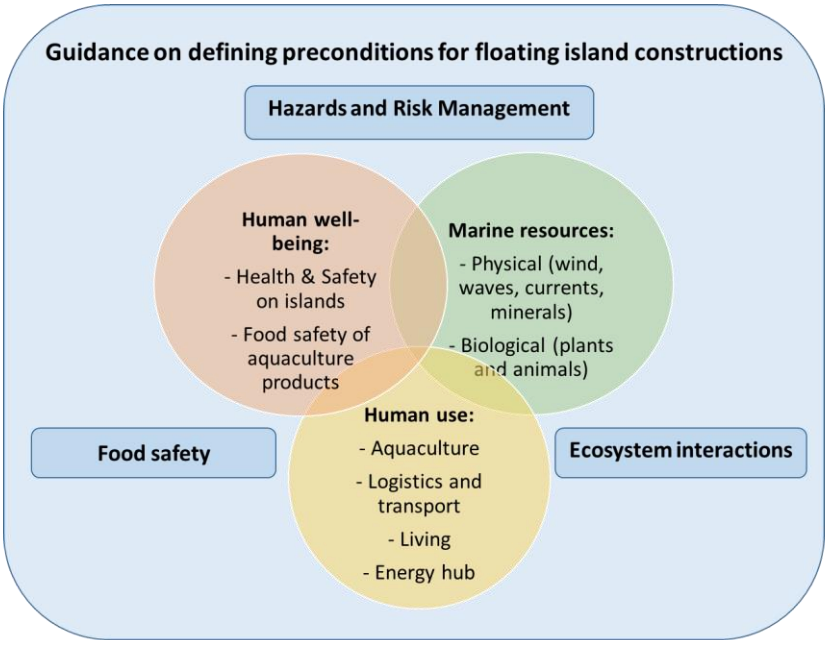
Executive Summary

This deliverable of the Space@Sea project provides guidance on Health, Safety and Environmental (HSE) aspects relevant to the design and application of floating modular islands. HSE requirements are very relevant aspects for the further development and future implementation of floating island constructions. The assessment of HSE issues is required to set standard preconditions for the floating island constructions. Particularly, the potential food and feed safety hazards as well as the associated environmental risks that may result from the multi-use platform environment is investigated.

The concise guidance presented here is based on different types of information:

- a hazard inventory (HAZID) elaborated in a risk register, and an evaluation of risks. This work is based on expert meetings and input from the four "application work packages" of the Space@Sea project, *i.e.* 'EnergyHub', 'Living', 'Farming' and 'Ports & Logistics'.
- an inventory of food safety issues in relation to multi-use of islands including aquaculture, based on literature study.
- an inventory of possible ecosystem-module interactions, *i.e.* the impact of the floating modules on the ecosystem, and the impact of the ecosystem on food production and the (integrity of) floating structures.

The guidance is presented in chapter 2 and is based on background information provided in the following chapters. The issues considered and their interactions are visualized in the figure below and elaborated in the report in chapters on hazards and risk management, food safety, and ecosystem interactions.



Hazard and Risk Management

Reference is made to general and industry specific guidelines for HSE from the World Bank Group (www.ifc.org/ehsguideline) for all the applications considered within Space@Sea, *i.e.* the EnergyHub@Sea, Living@Sea, Farming@Sea and Transport&Logistics@Sea, and potential interactions between these activities.

As general and industry specific HSE guidelines are already available, the focus of this guidance document is on the hazards related to the unique aspects of the floating modular island for offshore applications:

- Motions, induced by the floating conditions;

- Distance, because of offshore applications.

On the basis of the HAZID, potential hazards related to the above mentioned aspects are identified and classified according to a Risk Assessment – Hazard Catalogue (BG RCI A017e)

https://downloadcenter.bgrci.de/resource/downloadcenter/downloads/A017e_Gesamtdokument.pdf

The hazards are evaluated for their risk potential and conceivable prevention and mitigation measures are discussed.

The nature of identified hazards is very diverse, and related to workplace design, mechanical hazards, electrical hazards, hazards related to spill of substances, fire and explosions, physical impacts, mental stress factors and others.

In general, preventive measures can be taken by limiting certain operations to environmental boundaries (low waves and wind conditions), by securing any lose equipment and tools, using clean and anti-skid floors, and installing handles and rails. Many, but not all, of these preventive measures can be included in the design of the floating modules and their applications.

Mitigating measures can be taken in several ways, such as the training of people for these special working and living conditions, including planned evacuations. Also personal safety equipment may reduce the impact of incidents to people.

Food safety

The production of food at or in the vicinity of modular multi-use platforms may not only be facilitated but also be affected by other uses. This applies to the quality of food and feed products cultured at sea, where exposure to released materials and discharges may result in violation of quality standards. An overview of applicable standards is presented in this report. Standards apply to biological hazards, chemical hazards and physical hazards. Discharge of waste water and incidental spills from islands used for living and port operations may affect water quality. Also other pressures like noise may affect the growth and well-being of cultured organisms, including fish.

Ecosystem interactions

Interactions with the environment include the impact of operations on the marine ecosystem, as well as the environmental provisions (*e.g.* nutrients for seaweed culture) and the impacts of the marine environment on structures (*e.g.* salinity, fouling organisms). An overview is provided of the potential pressures that may arise from the presence and functions of floating islands at sea on the marine environment.

The aquatic environment itself may, or may not be a suitable place for the culturing of fish, mussels and seaweed. This depends on the environmental preconditions that should be met, such as the range in water temperature, salinity, and food availability. For a selection of aquaculture species considered relevant to the Space@Sea project, an overview of these environmental preconditions has been compiled.

Two types of environmental impacts related to the life-time and behaviour of offshore islands are relevant to consider: the effect of corrosion on the reinforcement of concrete, and the impact of fouling organisms. In order to minimize impacts on the structure, mitigating measures can be taken by setting up strategies for periodic inspection and maintenance of the floating structure and by covering of cracks in the concrete. Organisms attached to concrete structures, referred to as marine growth or fouling, may either protect or increase deterioration of their substrate. No clear conclusions can be drawn on whether fouling organisms should better be removed or not.

1. Introduction

1.1 Space@Sea

Space@Sea sets out to provide sustainable and affordable workspace at sea by developing a standardised and cost efficient modular island with low ecological impact. The consortium consists of a strong collaboration between 17 partners spread throughout Europe. Space@Sea will develop and demonstrate a modular floating island approach including four example applications which will result in business cases to be further detailed.

The commission urged in their BG4-2017 call that health and safety issues associated with multi-use marine platforms should be improved and that the environmental viability should also be investigated.

In Work package 2 of the Space@Sea project, health, safety and environmental issues are studied. In D2.1, an inventory of regulations was reported. In the current report, sets of indicators are developed on preconditions for health, safety and environment aspects to be considered in the development of the different types of modules.

1.2 Health, Safety and Environmental issues

Health, Safety and Environmental (HSE) requirements are very relevant aspects for the further development and future implementation of floating island constructions.

The assessment of HSE issues is required to set standard preconditions for the floating island constructions. Particularly, the potential food and feed safety hazards as well as the associated environmental risks that may result from the multi-use platform environment will be investigated.

HSE issues are inevitably linked to HSE risks. HSE risk relates to harm to persons or the environment due to the activities associated with the multiple-use platforms at all stages of the process from manufacturing to installation, operation and decommissioning. The recommended approach to assess HSE risks for this context takes into account the key standards and a recommended practice (ISO 12100, ISO 31000/ 31010, ISO 45001 standards and DNV GL Qualification of New Technology recommended practice) and also guidelines, standards and legal requirements specific to health and safety in the offshore construction, maritime and shipping sector. Environmental risk assessment (also known as ecological risk assessment) methodology has been developed on the basis of human health and safety methodology. The environmental risk assessment and management as part of the Space@Sea project is based on these guidelines, rules and regulations for environmental risk assessment and management.

An overview of regulations is provided in the Deliverable D2.1 of the Space@Sea project: “Inventory of regulations”.

1.3 Preconditions for floating island constructions

The preconditions for the actual design of the floating island constructions will be defined based on an analysis of legal requirements, and requirements as described above. In this task, preconditions will be identified that need to be taken into account for the specific business cases within Space@Sea as further defined in WP1, and to be elaborated in the dedicated WP6 through WP9. Relevant issues on health aspects include the impact of spending time at sea, medical care and quality of aquaculture products. For safety aspects, many regulations have been developed, and relevant topics need to be identified for constructions and operations as defined within Space@Sea. Interactions with the environment includes both the impact of operations on the marine ecosystem, as the environmental provisions (*e.g.* nutrients for seaweed culture) and impacts of the marine environment on structures (*e.g.* salinity, fouling organisms).

1.4 Structure of the report

The aim of this report is to provide guidance on the management of HSE aspects for the design and applications of floating modules. The concise guidance is presented in Chapter 2.

The guidance is based on information as detailed in the following chapters (see Figure 1 for a graphical presentation of the report structure). These chapters comprise:

- a hazard inventory elaborated in a risk register, with an evaluation of risks in accompanying texts (Chapter 3);
- food safety issues in relation to multi-use of islands including aquaculture (Chapter 0);
- ecosystem-module interactions, *i.e.* the impact of the floating modules on the ecosystem, and the impact of the ecosystem on food production and the (integrity of) floating structures (Chapter 5).

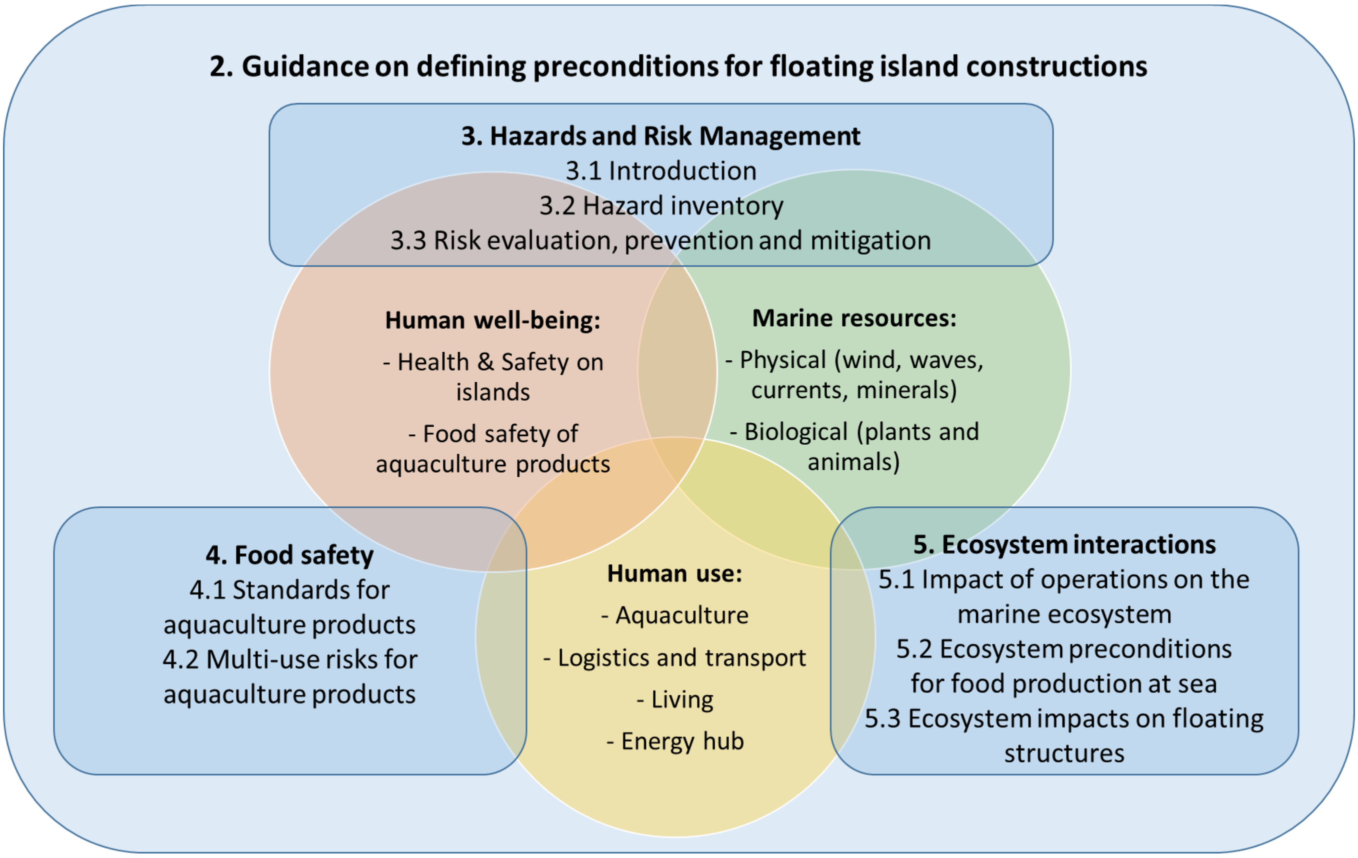


Figure 1 Schematic presentation of the issues involved with floating islands at sea in relation to the structure of this report; numbers are referring to chapters. Overall guidance, integrating all aspects involved with exploiting floating islands at sea, is provided in chapter 2. The main aspects are described in more detail in separate chapters. Human well-being (red top left circle), covering health and safety on the islands and food safety of aquaculture products, is affected by marine resources (green top right circle) and human use (yellow bottom circle). These interactions are described in chapter 3: Hazards and risk management and chapter 4: Food safety, respectively. The floating islands and their human use options (aquaculture, logistics and transport, living and energy hub) depend on - and are affected by - marine resources (wind, waves, currents, minerals, plants and animals). These interactions are described in chapter 5: Ecosystem interactions.

2. Guidance on defining preconditions for floating island constructions

2.1 Introduction

This guidance aims to create awareness on the main issues concerning health, safety and environmental aspects in relation to the design and applications of floating modular islands at sea.

Activities at sea, such as shipping, fishing, and work at oil and gas platforms, involves several risks to the people working there, to the infrastructure and equipment used, and to the surrounding environment. Many hazards have been identified already for these activities. General and industry specific guidelines for HSE, the World Bank Group Environmental, Health, and Safety Guidelines, which can be found at: www.ifc.org/ehsguidelines, are available. Information and guidance on HSE issues is thus readily available and it is not our intention to rewrite such existing documents. Instead, we provide an overview of the most relevant issues for the applications of the modular islands (section 2.2).

In section **Error! Reference source not found.** we focus on the hazards related to the unique aspects of the f loating modular island for offshore applications:

- Motions, induced by the floating conditions;
- Distance, because of offshore applications.

Events causing risks may occur in relation to these aspects of motion and distance. And since motions are mainly induced by sea state conditions, and thus by water currents and waves, also the likelihood and severity of motions depends on the frequency and intensity of risky conditions. The aspect of distance is related to the location of deployment of floating modular island, relative to facilities on the main land, such as ports or airports.

These factors make it impossible to quantify the possible risks. Another limitation for applying a detailed and quantitative risk assessment is the extent to which the islands and their applications are currently designed. This guidance, therefore, focuses on hazards and a qualitative evaluation of their risk level. In addition, the possibilities for managing risks by preventing risks to occur, or by minimize their consequences is evaluated. These should be considered in the further development of floating islands at sea.

The final section of this chapter (section 0) addresses multi-use risks, provides insight in the most relevant HSE issues.

2.2 General and industry specific guidelines for HSE

In this section we refer to the general and industry-specific guidelines for HSE from the World Bank Group (www.ifc.org/ehsguideline). Although for project development all HSE issues have to be considered, specific issues relevant for the applications of the modular islands are indicated in Table 1. There are different forms of relevance indicated in the table:

- Relevant (R): issues that are specifically relevant for the application
- Precondition (PC): issues that are essential for the functioning of the application
- Source (S): issues that are caused or increased by the functioning of the application
- Not specifically relevant (N): not specifically relevant for the application, but should be consulted.

To address these issues, the HSE Guidelines should be consulted, which are accessible for free at https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/policies-standards/ehs-guidelines.

Table 1 Overview of the HSE Guidelines (World Bank Group, 2007). For each application it is indicated whether the guideline is relevant (R), not specifically relevant (N), a precondition (PC: the guideline addresses issues that are essential for the functioning of the application) or a source (S: the guideline addresses issues that are caused or increased by the functioning of the application). It should be noted that these indications for relevance are intended to prioritise, i.e. *to highlight the main issues as guidance for the early stages of development of floating island constructions. For actual project developments, all HSE guidelines are relevant and should be addressed.*

HSE Guidelines	Energy hub	Living	Farming	Transport & logistics
General HSE Guidelines				
1 Environmental				
1.1 Air Emissions and Ambient Air Quality	N	PC	N	S
1.2 Energy Conservation	R	R	R	R
1.3 Wastewater and Ambient Water Quality	N	S + PC	S + PC	S
1.4 Water Conservation	R	R	R	R
1.5 Hazardous Materials Management	R	PC	PC	R
1.6 Waste Management	S	S + PC	S + PC	S
1.7 Noise	N	S + PC	S + PC	S
1.8 Contaminated Land	N	N	N	N
2. Occupational Health and Safety				
2.1 General Facility Design and Operation	R	R	R	R
2.2 Communication and Training	R	R	R	R
2.3 Physical Hazards	S + PC	PC	S + PC	S + PC
2.4 Chemical Hazards	R	PC	S + PC	S + PC
2.5 Biological Hazards	N	S + PC	S + PC	S
2.6 Radiological Hazards	N	N	N	N
2.7 Personal Protective Equipment (PPE)	PC	PC	PC	PC
2.8 Special Hazard Environments	R (Chapter 3)	R (Chapter 3)	R (Chapter 3)	R (Chapter 3)
2.9 Monitoring	R	R	R	R
3. Community Health and Safety				
3.1 Water Quality and Availability	N	N	S	S
3.2 Structural Safety of Project Infrastructure	R	R	R	R
3.3 Life and Fire Safety (L&FS)	R	R	R	R
3.4 Traffic Safety	R	R	R	R
3.5 Transport of Hazardous Materials	R	R	R	R
3.6 Disease Prevention	R	R	R	R
3.7 Emergency Preparedness and Response	R	R	R	R
4. Construction and Decommissioning (R, see WP3, 4 & 5)				
Industry Sector Guidelines				
Aquaculture			R	
Electric Power Transmission and Distribution	R			
Fish Processing			R	
Health Care Facilities		R		
Ports, Harbors and Terminals				R
Waste Management Facilities		R		
Water and Sanitation		R		

2.3 Risk factors for floating islands applications

The risk factors from the Risk Assessment – Hazard Catalogue (BG RCI A017e) which are relevant for floating island constructions, are listed in Table 2 (for an overview of risk factors see Annex 2).

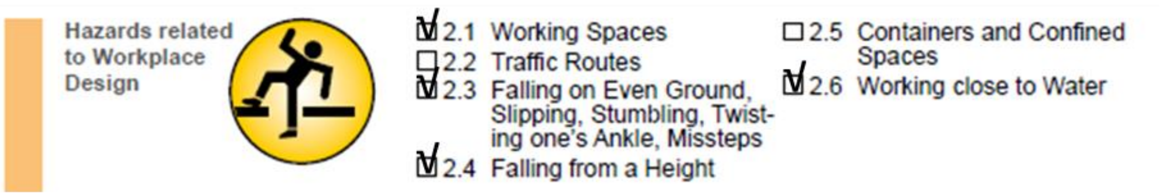
These risk factors are used in Table 3 to categorize the hazards identified for floating islands constructions (hazard inventory (HAZID), see Chapter 3 and Annex 3). In Table 3, for each relevant risk factor, the hazards as identified by the HAZID are listed, followed by the related risks. In addition, prevention and mitigation measures are described as a guidance to address these hazards and risks.

Table 2 Relevant risk factors from the Risk Assessment – Hazard Catalogue (BG RCI A017e). A complete overview of risk factors is presented in Annex 2

Risk factor No	Risk symbol	Risk factor
2		Hazards related to workplace design
4		Mechanical Hazards
5		Electrical hazards
6		Hazards related to substances
7		Hazards related to fire and explosion
9		Hazards related to special physical impacts
10		Mental stress factors
11		Miscellaneous risk and stress factors

Table 3 Hazards categorised according to the risk factors from the Risk Assessment – Hazard Catalogue (BG RCI A017e). Relevant risk factors are indicted by a tick mark "√". For each risk factor the hazards, risks, prevention and mitigation are described

Hazards related to workplace design



2.1 Working spaces

Hazard

Due to extreme wind and wave conditions divers may get entangled in nets of net-cages during maintenance operations.

Risk

Risk for people to get involved in accidents is mainly related to harsh environmental condition, *i.e.* the intensity of exposure to waves and wind. Also the design of the workspace may contribute to the risk.

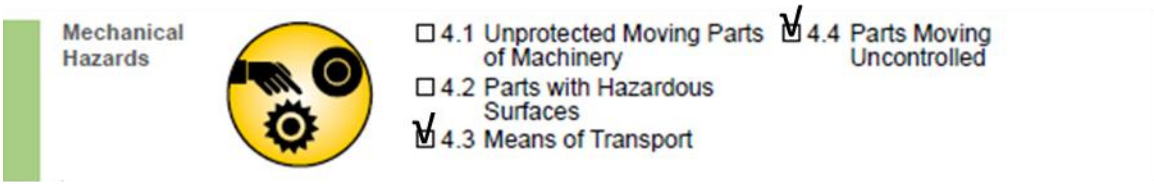
Prevention and/or mitigation

Prevention can be taken by limiting operations to environmental boundaries (low waves, wind) and to design the work space such that the risk of entanglement is minimalised, *i.e.* it should have sufficiently large dimensions to avoid entanglement, and equipment should be stored well organized.

2.3 Falling on Even Ground, Slipping, Stumbling, Twisting one's Ankle, Missteps

Hazard
Due to biofilm and/or liquids in combination with platform motions the deck becomes slippery;
Due to material fatigue the deck may become uneven;
Mishandling of lubricants during maintenance of any equipment can result in creation of slippery surfaces and greatly contribute to workplace/environmental pollution if they find their way into water;
Due to wet, iced conditions and motions people may slip on the helicopter deck.
Risk
The risk to people to get injured by falling may arise from slippery decks, caused by water, oily substances and biofilms that may develop. The risk increases due to motions
Prevention and/or mitigation
Preventive measures may be taken by regular cleaning and drying of floors, providing an anti-skid treatment of floors, taking up drain openings in the design, and by creating awareness of slipping and tripping hazards, and warnings not to run or jump. Mitigation measures could be taken by demanding the use of personal protective equipment (PPE), *e.g.* anti-slip safety shoes and helmet, especially in working areas where slippery conditions may occur.
2.4 Falling from a height
Hazard
Due to motions and extreme wind conditions people may fall from platform.
Risk
The risk is that people may fall from heights or from the island, due to unexpected motions or gusts of wind.
Prevention and/or mitigation
Preventive measures may be the placements of rails on the borders of the modules, and handles at relevant places where heights are present. Mitigating measures may be the installation of fixed ladders and handrails that provide access to the modules from the water. See also hazard category 2.6 below.
2.6 Working close to water
Hazard
Vessels colliding with platform due to strong wave conditions;
Due to motions and extreme wind conditions people may become trapped below or between platforms;
Ice drift colliding with platform due to strong wave conditions;
Due to high waves, water reaches the platform deck and steel containers on a steel deck without any lock will slip easily if the module is inclined.
Risk
The risk of activities close to water is that people or equipment may fall into the water. It may occur due to motions, induced by waves, wind or collisions. It may lead to injuries, drowning and loss of equipment. The latter may also result in environmental impacts.
Prevention and/or mitigation
Preventive measures may be taken by providing rails on the borders of the modules, securing equipment and by wearing fixed fall protection devices which secure people to the construction. Mitigation to reduce the impacts include the provision of PSEs in the form of life jackets. Furthermore, alarm and rescue measures need to be taken, including response plans, placement of adequate rescue equipment on the modules, and training of personnel in safe behaviour and emergency measures.

Mechanical Hazards



4.3 Means of transport

Hazard

Not sufficiently locked loads may fall from lifting gear due to uncontrolled motions.

Risk

The risk is that people in vicinity to the lift may get injured. The falling load may also cause damage to the structure, resulting in economic and possibly environmental impacts.

Prevention and/or mitigation

Prevention can be realised by installing adequate equipment. Mandatory testing of working equipment is necessary for all equipment used, and may be more stringent for applications at floating islands. Also the prevention of people being in the direct area of lifting gear is reuired.

Mitigation is hardly possible. The focus should be on the prevention of this hazard.

4.4 Parts moving uncontrolled

Hazard

Many of the identified hazards are related to uncontrolled moving. Hazards may be grouped as follows:

Failure of the mooring system

Due to the mooring failure the platform is drifting in an uncontrolled fashion;

Due to the mooring failure the platform is drifting off.

Failure of the connection system

Due to failure of the connection system modules separate or collide;

Due to failure of the connection system modules separate;

High wave loads result in damage to the structural connections of the wave energy converter(s), which may result in capsizing and sinking of module(s).

Swinging loads from cranes

Due to motions and extreme wind and wave conditions loads might swing uncontrollably and net cages may move unexpected;

The winding drums break of a crane has a mechanical failure or the line slips, in such a way that the load is not lost, but lowers uncontrolled;

During repair/change of moving parts of cranes, sea states and wind may cause uncontrolled motion;

Due to motions and extreme wind conditions loads from cranes might swing uncontrolled;

Motions affect carrying and lifting operations by persons and equipment leading to injuries of persons or damage to equipment.

Collisions

Damage caused by (sea-going) vessels and animals may disconnect or damage grid connection cable(s) of the electrical components of the wave energy converters;

Offshore operations may result in collisions with vessels or induce corrosion that may cause leakage of the floating modules, resulting in (partly) sinking.

Other failures and events

Due to excessive weight a module may start (partially) sinking. Partial sinking can also result in tilting of the module;

Shifting and falling of unfixed items due to the movements of modules;

Due to multiple mechanical systems vibrating in cohesion with wave vibrations mechanical resonance can occur;

Due to motions people may getting injured by sharp objects (knives, needles);

The hydrodynamic response of the platform and sea state in the berth behind floating breakwaters is very complex to model. Incorrect assumptions may cause installations to happen at environmental conditions that may cause uncontrollable motions and damage during installation of large structures and or smaller substructures;

Due to exceedance of limits or a power loss, the vacuum mooring systems may fail. This causes the ULCV to possible drift off due to wind and current;

Failure in the motion compensation systems and load control systems, *i.e.* due to power loss, multiple sensor failure, control system instability or other unexpected failures. May cause uncontrolled load motions.

Risk

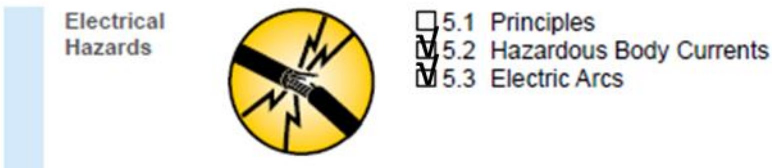
The risks are related to the behaviour of the floating system, equipment such as cranes and vessels as a result of uncontrollable motions that may occur as a result of sea state, *i.e.* motions induced by waves, currents and wind. The consequences are very diverse and include all assets considered (people, equipment, infrastructure and ecosystem), and the severity of consequences ranges from small personal injuries to the sinking of modules.

Prevention and/or mitigation

Some level of prevention can be achieved by ensuring stability of movements, by stabilizing equipment and loads, *e.g.* by installing these on the centre of modules, and to secure mobile tools to avoid falling or flying around. All of these hazards mainly involve the adequate design of the modules, their connection and mooring system, and of equipment. Their design has to fulfil safety requirements, including mandatory testing and the definition of mitigating measures in case of failure. The risk of collision may be prevented by installing tug boats that can respond in case uncontrolled vessels float in the direction of a floating island.

Mitigation is hardly possible. The focus should be on the prevention of these hazards. Clear procedures to handle in case of incidents may help to minimize consequences.

Electrical hazards



5.2 Hazardous body currents

Hazard

Due to storm conditions lightning strikes may occur on the platform;

Due to unexpected water hoses while working with feed tubes of aquaculture systems, workers may get exposed to voltage;

Environmental conditions or human mistakes may cause damage to power cable, an electrical component of the wave energy converter.

Risk

There may be conditions where the risk of hazardous body currents occurs by lightning and electrical resources used on the island. These may lead to severe impacts on people, including injuries and human fatalities.

Prevention and/or mitigation

Prevention is hard to achieve. Proper use of electrical resources is required and equipment should be regularly checked. Warning signs and safe distances between workers and electrical installations should be respected. Personnel protective equipment should be used where hazardous situations are foreseen. The island should be equipped with lightning rods to avoid lightening strokes.

Mitigation is possible to some extent by applying medical procedures for treatment in case of exposure to electricity.

5.3 Electric arcs

Hazard

Under storm wave conditions the generator of the wave energy converter is so heavily stressed that the electrical components are subjected to high thermal loads which may lead to fire.

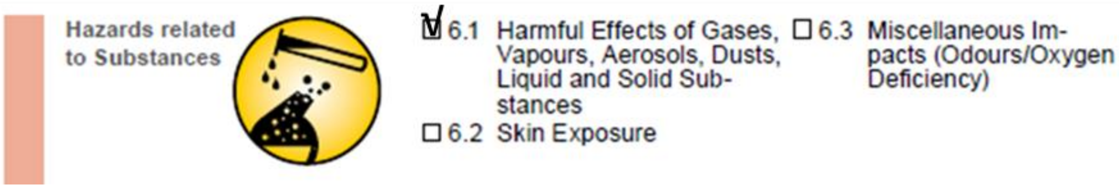
Risk

Risk of fire may occur as a result of electrical arcs caused by for instance short circuits.

Prevention and/or mitigation

Prevention can be reached by using adequate equipment. Mitigation can hardly be achieved. The response to fire is dealt with under hazard category 7 below.

Hazards related to substances



6.1 Harmful effects of gases, vapours, aerosols, dusts, liquid and solid substances

Hazard

Due to unexpected loadings induced by motions (or otherwise) the power transmission system of the wave energy converter may fail, which may result in release of hydraulic fluid to the environment;

Spills may occur that may pose a chemical hazard to food safety by the accumulation of toxins in seafood products. Also consider tainting (see OSPAR list of substances known to cause tainting);

Antifoulants can leach into the environment leading to a chemical hazard to food safety: the accumulation of toxins in seafood are hazards to the safety of aquaculture products;

Bacterial pathogens, such as *Enterococci* and *E. coli* from human sewage and animal feaces may enter the environment from *e.g.* wastewater, run-off from deck, sewage and boat discharge;

Small materials (*e.g.* glass, metal) that could be lost from the islands should be considered, as these may end up in aquaculture products and be swallowed by humans (via food) or animals (via feed).

Risk

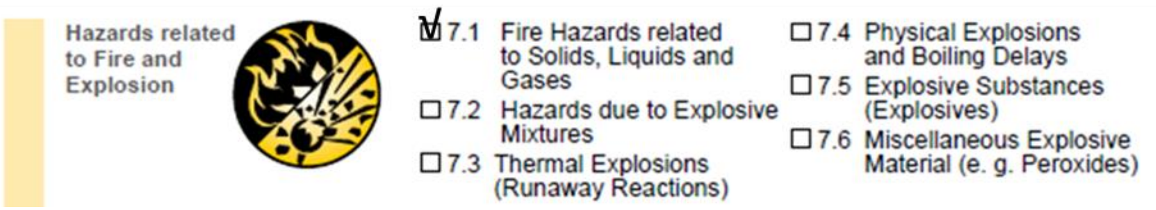
Risks of incidental spills may affect human health, cause effects on the ecosystem and affect the quality of products produced in aquaculture. Harsh environmental conditions increase the probability of spills to occur. In addition, also operational discharges, such as antifoulants and run-off water impact the ecosystem and aquaculture products.

Prevention and/or mitigation

Prevention measures may be taken by applying spill receiving systems that avoid spills from leaking overboard.

Mitigation could be achieved to some extent by setting up procedures for spill response and having spill response equipment available. Training is required to perform effective spill mitigating measures.

Hazards related to fire and explosion



7.1 Fire hazards related to solids, liquids and gases

Hazard

Fire due to human error or electrical or mechanical failure.

Risk

The risk of fire is very important to consider on modular floating islands, see also paragraph 3.2.2 under living@Sea, where risks and (preventive) measures are suggested, summarized from deliverable D7.2 of the Space@Sea project. Distance from the shore and firefighting facilities may increase the severity of the consequences of fire. An appropriate evacuation plan should, therefore, be in place and tested, including regular training of people.

Prevention and/or mitigation

In order to achieve the fire safety objectives (paragraph 3.2.2), the following functional requirements are recommended (D7.2):

- Division of the floating island into fire compartments with thermal and structural boundaries;
- Separation of accommodation spaces from fire hazardous spaces;
- Restricted use of combustible materials;
- Detection of any fire in the zone of origin;
- Containment and extinction of any fire in the space of origin;
- Protection of means of escape and access for firefighting;
- Ready availability of fire-extinguishing appliances; and
- Minimization of possibility of ignition of flammable cargo vapour.

Hazards related to special physical impacts

9.1 Noise

Hazard

Noise pollution caused by machinery and equipment.

Risk

Risk of noise is not related to motions and distance, and is, therefore, not different from on-land use of machinery and equipment. However, noise is important to consider in relation to human health and possible ecosystem effects. Especially sea mammals (whales, dolphins, porpoises, seals) are known to be sensitive to underwater noise.

Prevention and/or mitigation

Prevention measures include the use of low-noise design of equipment and (work) spaces, and avoid resonance by adequate installation of machineries on deck.

Mitigation can be achieved for working people by the use of hearing protection equipment.

9.3 Whole-body vibrations

Hazard

Due to platform motions the platform will vibrate, causing health problems that may also have economic impacts;

Installations on the island cause vibrations.

Risk

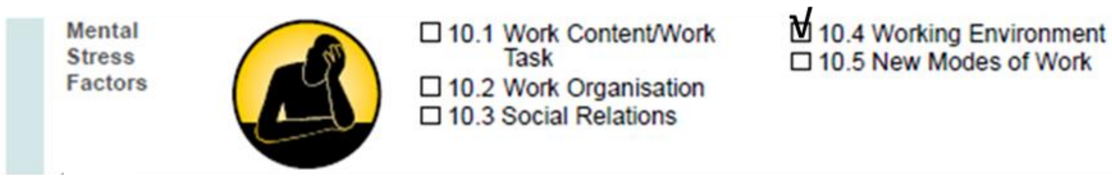
The risk of whole-body vibrations concerns the occurrence of vibrations affecting human health. These vibrations may be related to motions of platforms.

Prevention and/or mitigation

Prevention can be achieved by using installations, equipment and tools causing low vibrations. Also the fastening and buffering of connections between equipment and the modules may help to reduce vibrations. The behaviour of modules and their consequences for vibration should be modelled and tested carefully in order to reduce vibrations by the design of the modules and their layout.

Mitigation is hard to achieve, therefore, it is important to consider preventive measures.

Mental stress factors



10.4 Working environment

Hazard

Motion of module, might affect the crane drivers ability to control the crane.

Risk

The risk is that working people may get psychologically and physically stressed by motions that hinder them in doing their job. This may result in hazardous situations, especially for those applications where a hazard was already identified, such as for the use of cranes.

Prevention and/or mitigation

Prevention is possible by considering ergonomic viewpoints when planning working places, and reduce exposure of working people, e.g. by reducing shift times in relation to motions of the platform.

Mitigation seems hard to achieve.

Miscellaneous risk and stress factors

11.1 Field work

Hazard

Incorrect hydrodynamic assumptions in the simulation model may cause installations to happen at environmental conditions that may cause uncontrollable motions and damage during installation of large structures and or smaller substructures.

Risk

This hazard is caused in the design phase of the modules and installed installations, and not considered relevant here, since it should be assumed that simulations are carried out adequately, and are tested and approved before construction.

Prevention and/or mitigation

See above.

11.2 Humans

Hazard

The staff suffers diseases and accidents during their stay that cause downtimes.

Risk

The risk is that normal operations may not be carried out adequately, which may result in various cascading effects and incidents.

Prevention and/or mitigation

Prevention can be taken by carrying out regular health checks and an early warning system for diseases to occur (registration of illness factors).

Mitigation may be achieved by good health care on the island, and a replacement plan for people having crucial positions in the safe functioning of key operations on the island.

2.4 Multi use risks

When combining different applications, *i.e.* the use of modules as energy hub for living, farming and transport & logistics, risks may arise from one application to another. In Table 4 these interactions are described, including a reference to the HSE guidelines from the World Bank Group (www.ifc.org/ehsguideline), which may be consulted to address these issues. Some parts of the HSE Guidelines are not included in the table:

- Chapter 3 Community Health and Safety, because this concerns issues outside the project study area (*i.e.* external effects);
- Chapter 4 deals with Construction and Decommissioning which is addressed in WP3, 4 & 5.

The specific industry guidelines from the World Bank Group (www.ifc.org/ehsguideline) may also be consulted to adequately manage HSE issues. Relevant industry guidelines for the different applications are:

- Energy hub
  Environmental, Health, and Safety Guidelines for Electric Power Transmission and Distribution
- Living
  Environmental, Health, and Safety Guidelines for Health Care Facilities
  Environmental, Health, and Safety Guidelines for Waste Management Facilities
  Environmental, Health, and Safety Guidelines for Water and Sanitation
- Farming
  Environmental, Health, and Safety Guidelines for Aquaculture
  Environmental, Health, and Safety Guidelines for Fish Processing
- Transport & logistics
  Environmental, Health, and Safety Guidelines for Ports, Harbors and Terminals

Multi-use risks for aquaculture products are specifically addressed under food safety of aquaculture products (section 4.2).

Table 4 Risks posed by applications (listed as rows) to other applications (listed in columns). The last column refers to the HSE guidelines from the World Bank Group (www.ifc.org/ehsguideline) which may be consulted to address these issues.

<table>
<tr><th></th><th>Energy</th><th>Living</th><th>Farming</th><th>Transport & logistics</th><th>HSE Guideline</th></tr>
<tr><th rowspan="2">Energy</th><td rowspan="2"></td><td colspan="2">Hazardous waste from energy convertor/storage systems, pose a risk to human health and/or the environment (including aquaculture) if improperly managed</td><td></td><td>1.6 Waste Management</td></tr>
<tr><td>Exposed or faulty electrical devices can pose a serious risk to residents</td><td colspan="2">Exposed or faulty electrical devices, including underwater cables, can pose a risk to aquaculture constructions and operations/workers</td><td>2.3 Physical Hazards</td></tr>
<tr><th rowspan="2">Living</th><td rowspan="2"></td><td rowspan="2"></td><td>Domestic waste(water) poses a risk to aquaculture (contamination of food/feed) if improperly managed</td><td rowspan="2"></td><td>1.3 Wastewater and Ambient Water Quality; 1.6 Waste Management; 2.5 Biological Hazards</td></tr>
<tr><td>Domestic noise may affect growth and condition of aquaculture species</td><td>1.7 Noise</td></tr>
<tr><th rowspan="4">Farming</th><td></td><td>Operational waste(water) and noise may affect living conditions if improperly managed</td><td rowspan="4"></td><td></td><td>1.3 Wastewater and Ambient Water Quality; 1.6 Waste Management; 1.7 Noise</td></tr>
<tr><td colspan="2">Aquaculture facilities (e.g. nets, cages, ropes) pose physical hazards (potential for accident/injury) to residents and workers</td><td>Aquaculture facilities (e.g. nets, cages, ropes) pose physical hazards (potential for accident/injury) to workers</td><td>2.3 Physical Hazards</td></tr>
<tr><td rowspan="2"></td><td>Hazardous substances (pesticides, medicines) pose a risk to human health</td><td>Hazardous substances (pesticides, medicines) pose a risk to human health</td><td>2.4 Chemical Hazards</td></tr>
<tr><td>Introduction of non-indigenous species (via culture species transportation) may affect living conditions</td><td>Introduction of non-indigenous species (via culture species transportation) may affect port operations</td><td>2.5 Biological Hazards</td></tr>
<tr><th rowspan="4">Transport & logistics</th><td></td><td colspan="2">Emissions (air, water, waste, noise) from vessels and port operations may affect environmental (living, aquaculture) conditions if improperly managed</td><td rowspan="4"></td><td>1.1 Air Emissions and Ambient Air Quality; 1.3 Wastewater and Ambient Water Quality; 1.6 Waste Management; 1.7 Noise</td></tr>
<tr><td colspan="3">Port operations pose physical hazards (potential for accident, injury or illness) to residents and workers</td><td>2.3 Physical Hazards</td></tr>
<tr><td rowspan="2"></td><td colspan="2">Hazardous substances (oil or chemical spills) pose a risk to human health and/or environmental (living, aquaculture) conditions</td><td>2.4 Chemical Hazards</td></tr>
<tr><td colspan="2">Introduction of non-indigenous species (e.g. via ballast water or hull fouling) may affect environmental (living, aquaculture) conditions</td><td>2.5 Biological Hazards</td></tr>
</table>

3. Hazards and Risk Management

3.1 Introduction

In order to minimize risks associated with the installation and operations of floating modules, a first step is to identify hazards. A hazard can be defined as a “any situation, activity, procedure, piece of equipment/machinery (or organism) that may cause harm or injury to a person, or damage to equipment or infrastructure”. A hazard analysis can be performed in different ways. There are two well-known methods for identifying hazards:

- Data Driven Methodologies: Where recorded observations are available. This could include the outcome of investigations into past events where the risk has materialized.
- Qualitative Methodologies: Where hazards are identified based on discussions, interviews and brainstorming. Consultation with internal stakeholders and external experts is needed.

In our study, we performed a hazard inventory on the basis of qualitative methodologies, making use of the expertise made available in the different “application” work packages:

- energy hub, where a specific task (T6.6) was formulated on the development of a risk register in order to perform a risk assessment;
- living@sea, which included a task (T7.3) on comfort and safety requirements;
- farming@sea, from which experts are also involved in WP2;
- transport@logistics@sea, including several tasks with relevance to safety and health issues.

The following steps are a practical and effective way of controlling hazards:

Step 1: Identify the Hazard

Step 2: Assess the Risk

Step 3: Eliminate or Control the Hazard

3.2 Hazard inventory

The aim of this chapter is to identify hazards and risk related to the installation phase of islands and to the use of modules for the several applications being studied in Space@Sea. Here we use the following definitions:

- Hazard: A hazard is any situation, activity, procedure, piece of equipment/machinery (or organism) that may cause harm or injury to a person, or damage to equipment or infrastructure.
- Risk: A risk is the chance that an existing hazard may actually cause harm, injury, or damage.

3.2.1 Boundaries

Hazards and risks may occur in the construction, installation, operation and maintenance and the decommissioning phase of islands and its building blocks (modules) as being developed within the Space@Sea project. However, the current focus is on the operational phase of the applications of islands: energy hub (WP6), living at sea (WP7), aquaculture (WP8) and transport and logistics (WP9). Also the general installation and decommissioning processes of the modules and its mooring system (WP5) are considered as relevant phases. However, these have not been developed yet.

Many hazards have already been identified for operations on land, on fixed platforms and on ships. The International Maritime Organization (IMO) is safeguarding human life and the marine environment from all kinds of pollutions and accidents by its two pillars: SOLAS (International Convention for the Safety of Life at Sea) and MARPOL (International Convention for the Prevention of Pollution from Ships). See Annex 1 for a graphical presentation of the content of SOLAS and MARPOL. Since it is not the intention to repeat what has been laid down in these conventions, we limit ourselves to the specific issues relevant to offshore floating conditions for modular islands. Therefore, we focus on motions as a steering factor for hazards, as a consequence of the islands being floating (Figure 2). Because of the offshore conditions, distance may be relevant when it comes to consequences, i.e. when people or equipment need to be transported because of injury, sickness or damage, although these may be mitigated by having a hospital or medical unit on the floating island. Since motions and distance depend on the location and its environmental conditions where islands are deployed, also the probability of occurrence and size of impact, and consequently the risk, depend on the location. Thus, where the hazards are similar for all locations, the risks may vary.

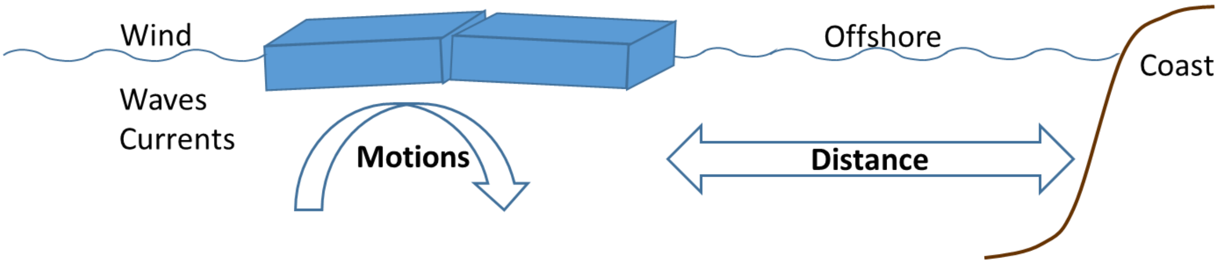


Figure 2 The focus on the main drivers for risk. Hazards may be caused by motions induced by wind, wavers and currents, and consequences may be related to the distance to coastal facilities.

As a general consequence of motions, materials may show fatigue sooner than under stable conditions. This may result in damage to equipment and infrastructure in general. In this assessment, we do not consider these impacts on the construction, since these are acknowledged in the design of the modules, and should be taken care of in the design of equipment used on the modules.

In conclusion, we make an inventory of hazards that result from the operational use of platforms for the various applications, and especially those that may not have been identified before.

The identification of hazards can be derived in various ways, *e.g.* use the experience of experts, information from past incidents and workplace injuries, product information (e.g. MSDS sheets, manuals), codes of conduct, descriptions of Best Available Technologies (BAT), common sense, et cetera. For the hazard identification we held an introductory workshop during the project meeting at Delft (November 2018), and a dedicated workshop on April 12, 2019 (in Delft, and with video connection) to discuss the methodology for the hazard inventory, including the final format for the a risk register, see below.

The aim of this hazard inventory is to identify health, safety and environmental risk related to harm to persons or the environment due to activities performed and associated with the floating substructures at all stages of lifecycle phases. The scope of the hazard assessment comprises 4 assets:

- People
- Equipment
- Infrastructure
- Environment

The term “Health” usually refers to people who suffer from injuries or health problems. The term “Safety” usually refers to equipment and infrastructure where accidents could occur. The term “Environment” usually refers to ecosystems which could be harmed by several events like shading, noise above and under water, discharges/ spills and waste. All of these were taken into account here.

In order to provide a structured inventory of hazards and risks we make use of a Risk Register. A Risk Register is defined here as a risk management tool to identify hazards and associated risks in order to define preventive and mitigation measures to reduce the risk. A format was selected from previous studies and further adapted for use in the Space@Sea project.

Each hazard is described and assessed in a similar way. For the Risk Register, the following fields are defined (Table 5).

Table 5 Fields used in the Risk Register

System	The largest level of system or process where the hazard is related to
Subsystem	The smaller level of system or process where the hazard is related to
Component	The specific piece of infrastructure or equipment the hazard is related to
Subcomponent	The specific part of the infrastructure or equipment the hazard is related to
BG RCI 017	Reference to the chapter in document Risk Assessment –Hazard Catalogue[1], see Annex 2.
Cause of hazard	The process or entity where the failure where the hazard derives from
Name of hazard / risk	Short description (name)
Description of hazard	Detailed description of the hazard
Type of hazard	The subject of the hazard, i.e. people (health, injury), Equipment (safety), Infrastructure (safety), Ecosystem (Environment)
Risk dimension / consequence	Indication of the possible (level of) consequences to people, equipment, infrastructure, environment.

[1] Risk Assessment –Hazard Catalogue A 017e Edition: October 2017, Berufsgenossenschaft Rohstoffe und chemische Industrie.
https://downloadcenter.bgrci.de/resource/downloadcenter/downloads/A017e_Gesamtdokument.pdf

The Basic hazard catalogue BG RCI A017 was used to support a systematic selection of possible hazards. The catalogue describes possible risk and stress factors and provides examples for safeguard measures, *i.e.* possible prevention and mitigation (including legal bases). It contains the following factors for the risk assessment:

- Basic Organisational Factors
- Hazards related to Workplace Design
- Hazards related to Ergonomic Factors
- Mechanical Hazards
- Electrical Hazards
- Hazards related to Substances
- Hazards related to Fire and Explosion
- Biological Hazards
- Hazards related to Special Physical Impacts
- Mental Stress Factors/ Miscellaneous Risk

Prevention and mitigation

The event of damage to occur may be controlled by:

- Taking preventive controls to remove the cause of the hazard, *i.e.* the source of the risk;
- Taking mitigation controls to reduce the consequence of the hazard, *i.e.* the impact.

The Risk Assessment – Hazard Catalogue (BG RCI A017e) provides for each hazard category examples for safeguard measures that can be considered as preventive and mitigation measures.

3.2.2 Hazards from the applications of modules

The different applications of the modules considered in this Space@Sea project may require specific considerations with regard to Health, Safety and Environmental issues. These are partly covered in the deliverables of the relevant work packages.

Energy hub

In Task 6.6, a methodology for hazard identification, risk estimation, risk evaluation and risk treatment will be described and applied to equipment and operations used for the different systems involved in the energy hub. These include the wave energy converter, electrochemical storage system and wind turbine. For each hazards a risk assessment will be applied by considering the probability of failure to occur, and the severity of its consequences.

The HSE inventory report in Space@Sea Deliverable 2.1 (2018) outlines relevant standards and regulations for offshore accommodation modules. The HSE inventory report describes all HSE related issues that are strictly considered while designing the energy hub. Main issues are:

- Sufficient number of personnel to detect possible accidents and incidents in time;
- Boat landing area coated with wearing/slip-resistance material;
- Lifesaving equipment like life boats are easily accessible;
- Adequate fire protection, fire extinguishing gas and fire alarms are properly installed;
- Safe escape routes are designed;
- Clearance around all electrical and machinery equipment to minimize long-term exposure to electromagnetic fields;
- Large cabins for additional persons in the case of an emergency;
- Prohibition signs are clearly marking overall working areas;
- Qualification of personnel working on the hub will meet HSE requirements.

Improvement in HSE related issues and saving number of trips required reinforces the definition of the energy hub.

Living@Sea

For living conditions, other requirements apply in comparison to working conditions. Not only safe, but also comfortable living standards need to be fulfilled in order to make floating island suitable for human inhabitation. The aim is to develop new technology that enables a more permanent living/working environment, that is safe and comfortable. Within the work package, several hazards were identified and described in Deliverable 7.2 (A catalogue of technical requirements and best practices for the design). Here, the main safety issues from Deliverable 7.2 are briefly described. In case of offshore living spaces (placed on living islands – Space@Sea), hazards are:

- occupational accidents;
- fires;
- structural failure (quite rarely);
- collisions with ships;
- extreme weather.

A major issue is fire safety which is identified, as the largest hazard for offshore operations. Fires on board can be of different sources/placement: electrical fires; accommodation fires; heating system fires; machinery fires; workshop fires. A list of fire-fighting systems and equipment that are usually used on board of (oil & gas) offshore units which can serve as an example for the floating islands, is included in D7.2. Some of the systems and equipment (*e.g.*, fire doors, fire dampers, hydrants, hose and nozzles, extinguishers, fire outfits) will be mandatory found in the living and working areas of the floating islands. Protection priorities during fire are, in order of appearance: human lives, environment, property (unit/ship). These priorities to protect on board are not only concerning units/ships fire incidents, but also other incidents such as grounding and collision.

Although the probability of fires expected on the Living@Sea islands is kept low, impact of a fire will be higher as more people will be affected. Therefore, it is of paramount importance to keep the following fire safety objectives in mind:

1. Prevent the occurrence of fire and explosion;
2. Reduce the risk to life caused by fire;
3. Reduce the risk of damage caused by fire to the offshore unit/ship, its cargo and the environment;
4. Contain, control and suppress fire and explosion in the compartment of origin; and
5. Provide adequate and readily accessible means of escape for passengers and crew.

ln order to achieve the fire safety objectives set out above, the following functional requirements are stated in D7.2:

- Division of the floating island into fire compartments with thermal and structural boundaries;
- Separation of accommodation spaces from fire hazardous spaces;
- Restricted use of combustible materials;
- Detection of any fire in the zone of origin;
- Containment and extinction of any fire in the space of origin;
- Protection of means of escape and access for firefighting;
- Ready availability of fire-extinguishing appliances; and
- Minimization of possibility of ignition of flammable cargo vapour.

Farming@Sea

The identification of hazards and risk has not explicitly been defined as a task for Farming@Sea (WP8). A concise literature overview is presented below in order to qualitatively describe the main hazards arising from aquaculture.

Myers *et al.* (2010) were the first to review the hazards in aquaculture. They stated that comprehensive studies of the hazards in aquaculture have not been conducted, and substantial uncertainty existed about the extent of these hazards. Their review provided an overview of causes of death, nonfatal injuries, and risk factors. More recent, attention for these issues increased (De Oliveira *et al.* (2017), Holen *et al.* (2018a, 2018b), Mitchell & Lystad (2016), Workers Compensation Board of Prince Edward Island (2008)). From this, a list of many (more than 50) catchwords related to potential hazards or factors contributing to hazards arising from aquaculture activities can be compiled. The frequency of occurrence and the risk for humans differs greatly among these hazards. This also depends on the type and location of the aquaculture. Offshore aquaculture may face bigger risks than inshore aquaculture due to harsher weather conditions, currents, transport distances, *etc*. Registered injuries and fatalities in aquaculture at sea would provide much insight into the actual risks for humans, however, only very few publications are available (Myers & Durborow 2012; Holen *et al.*, 2018a, 2018b).

Holen *et al.* (2018a) present an overview of reported injuries in the Norwegian aquaculture industry in the period 2001-2014 focusing on the production of Atlantic salmon and trout. The data sets on occupational injuries and serious injuries provide information about mode of injury, type of injury, affected body parts, and time of year of the reported injuries. The mode of injuries in aquaculture are listed in order of descending frequency:

> Fall; Blow from object; Entanglement or crush; Prick/cut/puncture; Other; Chemicals; Lift/carrying; Collision; Overturn; High/low temperature; Explosion/fire; Voltage.

In addition Holen *et al.* (2018b) present an overview of reported fatalities in the Norwegian aquaculture industry based on the data on fatalities from 1982 to 2015 registered by SINTEF Ocean. They also provide information on the incidents leading to fatalities, activities conducted at the time of fatalities and the time of year the fatalities were registered. This aids to determine the most important current safety challenges and to develop efficient safety management in aquaculture. The type of fatal incident types are in order of descending frequency:

> Loss of vessels; Blow from object/crush; Man overboard; Diving accident; Explosion; Collision; Traffic accident; In offshore caged aquaculture; In longline and rack aquaculture.

Holen *et al.* (2018a, 2018b) found a decrease in fatality rate in the last 15 years, which was related to the implementation of certification and management standards, and the introduction of new safety related regulations. There has been a change in the incidents leading to fatalities in the 30-year period studied. In the 1980s and 1990s, loss of vessel during transport was the largest cause of fatalities. In the last 2 decades, work operations, often assisted by cranes, were the largest cause of the fatalities. The number of fatalities increased in the autumn and winter months when the weather is harsher than during the rest of the year. This coincided with the fish escape statistics, which needs acute maintenance. Holen *et al.* (2018b) recommend to prioritize this conflict of interest to be further explored for safety consequences. In order to reduce risks of aquaculture for humans there are tremendous needs in Norwegian aquaculture to apply automated and autonomous systems to reduce the exposure of the workers to the harsh environment, increase the weather window for operations and reduce cost (Yang *et al.*, 2018).

Mitchell & Lystad (2019) quantified the incidence and characteristics of work-related injury and disease in the aquaculture and related service industries in Australia in a 4-year period. There were two fatalities, one in the offshore longline and rack aquaculture, and one in the offshore caged aquaculture. The most occurring causes of injuries and disease were falls, trips and slips, hitting objects with a part of the body, being hit by moving objects, and body stressing.

For identification of the hazards and specification of the precautions that need to be taken for the safe operation of equipment and tools and the safe handling of substances (fuel, chemicals, and antibiotics) in aquaculture carried out from floating island constructions, it can be recommended to utilise some existing tools and safety plans for aquaculture at sea. A good starting point would be the Prince Edward Island Aquaculture Occupational Health and Safety Code of Practice (Workers Compensation Board of Prince Edward Island (2008).

Transport&Logistics@Sea

Although hazards are not explicitly reported in WP9 on Transport & Logistics, the design of equipment and operations is taking care of the environmental boundaries, such as limits set by motions. In addition, preventive measures are defined, including maintenance and inspections, in order to repair faults and tackle failures.

Specifically, cranes of the Ship To Shore (STS) and Rail Mounted Gantry (RMG) are considered. Several measures have been defined (D9.5), including the following: “Routine checks and scheduled maintenance program is required to keep operating licences valid. If applicable, components need to be replaced and repair of the hydraulic engines, gear boxes, winches and slewing gears. The steel structures may need overhauling (coating and painting). After accidents inspection of damages and repairs are required”.

Considering hazards for transport and logistics there are three phases to distinguish (Figure 3):

- Ship operations
- Ship – platform operations
- Platform operations

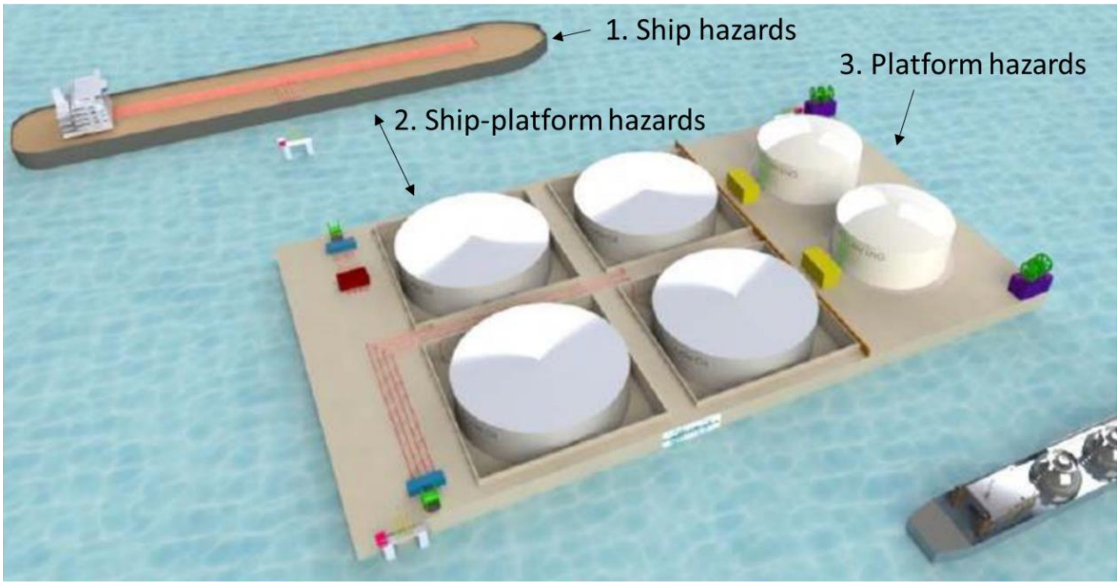


Figure 3 Illustration of liquid bulk storage, showing the three operational phases regarding hazards. (figure adapted from D4.2).

Ship operations

Ship operations are described in D9.3 and D9.4. Ship operations are affected by (seasonal changes of) environmental conditions, *e.g.* the water depths at inland waterways and the wave conditions at sea. As tailored Sea-Going Inland vessels are considered as a viable and economical transportation mode, the operation of those vessels at restricted sea areas leads to additional limiting criteria (*i.e.* stability issues, freeboard and bow height conventions, structural strength, seaworthiness and safety equipment). A minimum forward speed is demanded to maintain adequate manoeuvrability of a vessel. A speed loss of equal or more than 50% is assumed to be the operational limit. Environmental conditions determining the operational limits are described in D9.4.

Ship-platform operations

A main hazard issue regarding transport and logistics are the relative motions between a moored ship and the terminal. The relative motion between ship and terminal can be influenced by the degree of loading of the ship, local water levels, waves and currents.

Waves have the highest impact on the efficiency of platform-vessel container transfer operations. Therefore, the relative motions between the crane tip and the vessel induce the largest reduction in workability. The effect of wind and wave states on crane productivity is described in D9.4. The time required for vessels (up to 6000 TEUs) to complete both the loading and unloading process of its containers from/to the offshore floating platform is estimated in D9.4 at:

- 2.5 to 7.5 hours (no wind)
- up to 8.47 hours (lowest wind speed)
- up to 28.20 hours (highest wind speed).

Platform operations

The operability on board is defined by operating conditions which can be motion amplitudes, accelerations, etc. and based on: cargo safety, equipment, personal safety and efficiency. Limits for wave height, wind speed and current speed determining the operability on board are provided in D9.2.

3.3 Risk evaluation of identified hazards

The hazard inventory (HAZID) has resulted in a list of hazards which are documents in the Risk Register, see Annex 3. The hazards are evaluated with regard to their occurrence, probability, prevention and mitigation.

In the Guidance (Chapter 2), the hazards are categorized according to the factors elaborated in the Risk Assessment – Hazard Catalogue (BG RCI A017e). For an overview of risk factors, see Annex 3.

3.4 Minimizing Health, Safety and Environmental risks

Apart from the identification of hazards, measures to minimize potential risks should be taken. Minimizing risks include the prevention of hazardous events to happen, or to mitigate their consequences.

Bow-tie analysis is listed as a risk assessment technique of the IEC/ISO 31010:2009 standard (IEC/ISO 2009) and is defined as (IEC/ISO 31010:2009):

"*A simple diagrammatic way of describing and analysing the pathways of a risk from hazards to outcomes and reviewing controls. It can be considered to be a combination of the logic of a fault tree analysing the cause of an event (represented by the knot of a Bow-tie) and an event tree analysing the consequences*."

The Bow-tie analysis is particularly applicable to assessing and evaluating the effectiveness of existing controls. As a controls assessment tool, it is considered as a valuable approach in the determination of the nature and degree of uncertainty related to the pathways of risk and their controls (ICES, 2014;Figure 4).

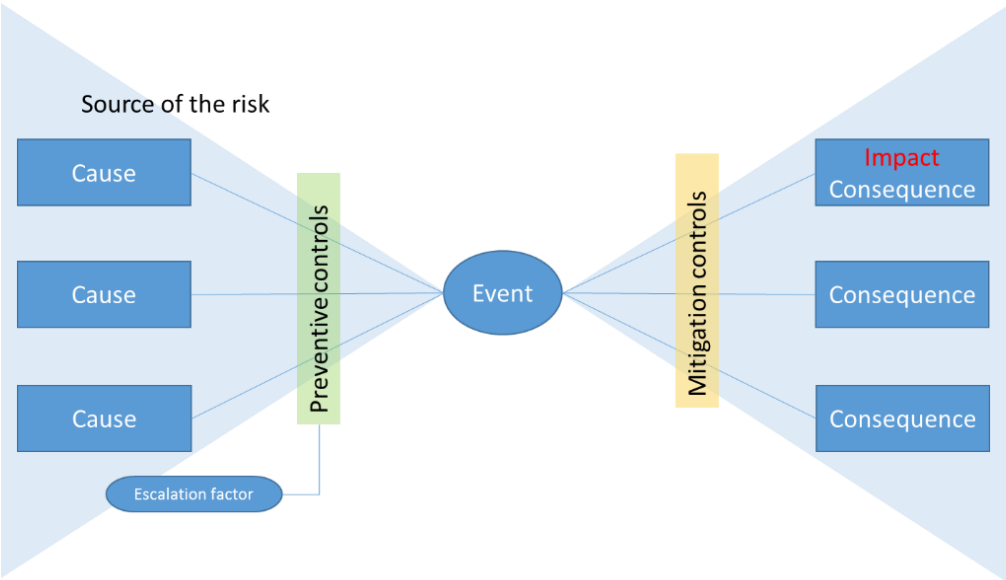


Figure 4 Bowtie analysis conceptual diagram. It should be noted that the origin name for the method is based on the fact that it looks like a Bow-tie.

The Bow-tie consists of plausible risk scenarios within a certain context, and illustrates ways in which an organization can take action to prevent these scenarios from happening or enhance their readiness to respond if they occur (ICES, 2014). It contains several key elements that are crucial for its proper use as a risk management methodology (ICES, 2014;Figure 4):

- Hazard: A hazard is technically the source of the risk that can cause the undesired event. An adequate description of the source of the risk should not be too specific (generating a lot of small hazards difficult to manage) or be too generic (not framing the risks of concern).
- Undesired Event or "Top Event": The undesired event is the top event that describes the loss of control over the hazard or the risk source.
- Consequences: The consequences are the potential harmful impacts that may occur as a result of the top event. A top event can lead to multiple consequences.

- Causes: Based on the source of the risk, each cause represents a scenario that can lead to a top event. There may be multiple causes that can independently bring about the top event. The causes may also occur at different time scales, and in some cases can take several years before they manifest themselves.
- Barriers: On the left side of the top event, barriers are the prevention controls inserted to reduce the likelihood of a top event occurring. On the right side of the top event, additional barriers are the mitigation and recovery controls inserted to reduce the repercussions or severity of the consequences as a result of a top event. Typically, the repercussions and the severity of the consequences may be expressed in terms of people, assets, environment, and reputation. Based on all potential scenarios, barriers are implemented to act on all possible links between the causes, the top event and the potential consequences.
- Escalation factors: These are factors that can undermine the effectiveness of a barrier or cause it to fail. Escalation factors are important elements to consider in a Bow-tie analysis as they focus attention to intrinsic design weaknesses as well as to outside influences. A third set of barriers is placed between a barrier and an escalation factor. These barriers are meant to prevent the escalation factor from causing the other barriers to fail (*e.g.* reduce the likelihood of a barrier failing).

3.5 References

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4. Food safety of aquaculture products

The production of food at modular platforms may be an opportunity to increase production at sea, and reduce costs by multi-use of these platforms, which enables the share of, for instance energy supply, transport, workers, and accommodation. Potential releases of materials and discharges of water from platforms may result in the exposure of organisms being cultured for use as food or feed. These hazards are dealt with in this chapter, by compiling standards for different types of food related hazards and by evaluating potential discharges from multi-used platforms.

4.1 Standards for aquaculture products

A variety of food-borne hazards[1] are of concern for aquaculture products (FAO & WHO, 2006). The hazards specifically relevant for aquaculture at floating island constructions are listed below:

- Biological hazards
    - Bacteria and viruses
- Chemical hazards
    - Environmental contaminants
- Physical hazards
    - Metal, glass, stones

4.1.1 Biological hazards

The environmental and human factors that influence microbial water quality must be considered for aquaculture. Influences on bacterial pathogens and indicator organisms, such as Enterococci and *E. coli*, originate from human sewage and animal faeces. These can enter waterways from wastewater treatment works, sewage and storm tank overflow and boat discharge, among sources (Science for Environment Policy, 2015). For floating islands, human sewage is a potential nearby source when other use options involve human presence, especially for domestic residence, but also for harbours.

Human wastewater can result in an actual risk to public health only if all of the following occur (Mara & Cairncross, 1989):

a) either an infective dose of an excreted pathogen reaches the aquaculture site, or the pathogen multiplies at the site to form an infective dose;
b) the infective dose reaches a human host;
c) the host becomes infected; and
d) the infection causes disease or further transmission.

If (d) does not occur, then (a), (b) and (c) can pose only potential risks to public health. Moreover, if this sequence of events is broken at any point, the potential risks cannot combine to constitute an actual risk (Mara & Cairncross, 1989).

It should be noted that enteric viruses and bacteria survive for considerably shorter periods in seawater than in fresh water, as described by Edwards (1992):

- Bacteria

  Fecal coliforms undergo a 90 percent reduction in 0.6-8 hours in seawater, compared to 20-100 hours in fresh water. Fecal streptococci and salmonellae may survive a little longer than fecal coliforms in seawater.

[1] A food-borne hazard is defined as “a biological, chemical or physical agent in, or condition of, food, with the potential to cause an adverse health effect” (FAO & WHO, 2006).

- Viruses
  Enteroviruses survive longer in seawater than excreted bacteria. They undergo a 90 percent reduction in 15-70 hours in seawater, still considerably shorter than their survival in fresh water.
- Protozoan cysts and helminth eggs.
  The survival of protozoan cysts and helminth eggs is similar in seawater to fresh water, but they present little health hazard because they tend to settle out.
- The elimination rate is much faster in warm than in cool seawater, for both excreted viruses and bacteria.

Mussels
Shellfish are filter feeders and concentrate bacteria and viruses in their tissue, mainly in the digestive system, at levels more than 100-fold higher than in the surrounding seawater (Edwards, 1992). Furthermore, shellfish are often eaten raw or only lightly cooked. Diseases associated with excreted virus contamination of shellfish is mostly hepatitis A, but salmonelloses and enteric fevers, and poliomyelitis have also been associated with consuming shellfish from fecally polluted waters (Edwards, 1992).

Fish
The intestinal bacteria and viruses of humans do not cause disease in fish but they may be passively transferred to humans by fish. Water-based helminths parasitic to humans may be transmitted by fish which act as worm intermediate hosts, for instance, liver flukes (Edwards, 1992). Bacteriological examinations of fish cultured at wastewater-fed marine ponds revealed significant numbers of Enterobacteriaceae in the digestive tracts, although none were found in samples of kidney, liver and spleen (Edwards, 1992).

Seaweeds
No information seems available on the risk for diseases by seaweed consumption as a result of bacteria and viruses. There are two reasons which reduce potential risks: Seaweed are always washed prior to consumption (washing off potential bacteria such as Vibrio's); Seaweed seem to have antimicrobial compounds, which may lead to less bacteria.

Food safety criteria

Commission Regulation (EC) No 2073/2005 on microbiological criteria for foods (EC, 2005) lays down food safety criteria for relevant foodborne bacteria, their toxins and metabolites, such as *Salmonella*, *Listeria* monocytogenes, *Enterobacter sakazakii*, staphylococcal enterotoxins and histamine in specific foods. These criteria are applicable to products placed on the market and define the acceptability of a product or a batch of food. The activities performed to ensure the application of food and feed law are laid down in Regulation (EU) 2017/625 (EC, 2017a).

Besides the safety standards in food, microbial quality targets have been established for the environment that can be used to facilitate compliance with the health-based targets, *e.g.*, viable trematode eggs not detectable (number per 100 ml or per g total solids, or $\leq 10^4$ *E. coli* (arithmetic mean number per 100 ml or per g total solids) and ≤ 1 helminth egg (arithmetic mean number per litre or per g total solids) in aquaculture water to protect consumers (Edwards, 2008).

4.1.2 Chemical hazards

Toxicological standards are available for fish, mussels and seaweeds/microalgae as food, food additive or feed product. It should be noted that contaminant levels in aquaculture products vary seasonally, as shown by Jansen *et al.* (2019) for offshore culture of seaweed.

Food

The basic principles of EU legislation on contaminants in food are laid down in Council Regulation 315/93/EEC (EC, 1993):

- Food containing a contaminant to an amount unacceptable from the public health viewpoint and in particular at a toxicological level, shall not be placed on the market;
- Contaminant levels shall be kept As Low As can Reasonably be Achieved (ALARA) following recommended good working practices;
- Maximum levels must be set for certain contaminants in order to protect public health.

Maximum levels for certain contaminants in food are set in Commission Regulation (EC) No 1881/2006 (EC, 2006). As an indication for guidance, standards for the foodstuffs related to (shell)fish and seaweed are included in Table 6.

Table 6 Maximum levels for certain contaminants in foodstuffs (EC, 2006). Only foodstuffs related to (shell)fish and seaweed are included in this table. There are many notes and exemptions listed in Commission Regulation (EC) No 1881/2006. The foodstuffs and corresponding levels reported here serve as an indication for guidance. Always consult the original regulation to check for specific levels and conditions. The maximum levels apply to the edible part of the foodstuffs concerned, unless otherwise specified. Levels expressed in wet weight (ww) or fat are indicated.

Foodstuffs	**Contaminant**	**Maximum levels**
Bivalve molluscs	Benzo(a)pyrene	5.0 µg/kg
	Sum of benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene and chrysene	30.0 µg/kg
	Cadmium	1 mg/kg ww
	Lead	1.5 mg/kg ww
Cephalopods	Cadmium	1 mg/kg ww
	Lead	1 mg/kg ww
Crustaceans	Lead	0.5 mg/kg ww
	Cadmium	0.5 mg/kg ww
Fish		
Fish liver	Sum of dioxins and dioxin-like PCBS (WHO- PCDD/F-PCB- TEQ)	20,0 pg/g ww
	Sum of PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180 (ICES – 6)	200 ng/g ww (38)
Muscle meat	Lead	0.3 mg/kg ww
	Cadmium	0.05 mg/kg ww
	Mercury	0.5 mg/kg ww
	Sum of dioxins (WHO-PCDD/ F-TEQ)	3,5 pg/g ww
	Sum of dioxins and dioxin-like PCBS (WHO- PCDD/F-PCB- TEQ)	6,5 pg/g ww
	Sum of PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180 (ICES – 6)	75 ng/g ww
Smoked fish	Benzo(a)pyrene	2.0 µg/kg
	Sum of benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene and chrysene	12.0 µg/kg
Seaweed (food supplements)	Cadmium	3 mg/kg ww
Marine oils (fish body/liver oil and oils of other marine organisms intended for human consumption)	Sum of dioxins (WHO-PCDD/ F-TEQ)	1,75 pg/g fat
	Sum of dioxins and dioxin-like PCBS (WHO- PCDD/F-PCB- TEQ)	6,0 pg/g fat
	Sum of PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180 (ICES – 6)	200 ng/g fat

Feed

Aquaculture products intended for animal feed are also subjected to quality standards. Directive 2002/32/EC (EC, 2002) applies to products intended for animal feed and sets maximum levels of undesirable substances (Table 7).

Table 7 Maximum levels of undesirable substances in animal feed (EC, 2002). Only feed materials and substances that could potentially be related to fish/shellfish/seaweed are listed. Lowest level is reported when multiple conditions apply. Always consult the original Directive to check for specific levels and conditions

Products intended for animal feed	Undesirable substances	Maximum content in mg/kg (ppm) relative to a feedingstuff with a moisture content of 12 %
Complementary feeding stuffs	Fluorine	125
	Lead	10
Complete feeding stuffs	Arsenic	2
	Cadmium	0.5
	Fluorine	50
	Lead	5
	Mercury	0.1
	Nitrites	15 (expressed as sodium nitrite)
Feed materials	Arsenic	2
	Cadmium	1
	Fluorine	150
	Hexachlorobenzene (HCB)	0.01
	Hexachlorocyclo-hexane (HCH)	0.005 – 2.0
	Lead	10
	Mercury	0.1
	Various pesticides	0.005-0.5
Fish meal	Nitrites	60 (expressed as sodium nitrite)

4.1.3 Physical hazards

Waste discharge into the sea is allowed by MARPOL[2] (IMO, 1973) under certain conditions which often concerns the distance to shore. Although Space@Sea aims for zero discharge from the floating islands (through re-use and recycling), waste discharge from other sources, for instance ships passing by, cannot be excluded. In general, more is allowed with increasing distance to shore. According to MARPOL Annex V the discharge of glass, stones and metal is allowed with an offshore distance of > 12 nm and the discharge of such items that are broken or crushed with a thickness < 25 mm are allowed with an offshore distance of > 3 nm. The distance to shore of the floating islands construction is thus relevant for the potential of physical hazards for aquaculture products.

4.1.4 Water quality legislation

The quality of aquaculture products is not only regulated via standards (maximum levels) in food and feed products. Various EU policies are addressing seafood contamination from environmental pollution, such as the Shellfish Waters Directive, the Water Framework Directive, the Bathing Water Directive and the Urban Waste Water Directive. The latter two specially address pollution from sewage. Furthermore, the Marine Strategy Framework Directive (MSFD) requires Member States to ensure that contaminants in fish and other seafood for

[2] The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. The MARPOL Convention was adopted on 2 November 1973 at IMO. The Protocol of 1978 was adopted in response to a spate of tanker accidents in 1976-1977. As the 1973 MARPOL Convention had not yet entered into force, the 1978 MARPOL Protocol absorbed the parent Convention. The combined instrument entered into force on 2 October 1983. In 1997, a Protocol was adopted to amend the Convention and a new Annex VI was added which entered into force on 19 May 2005. MARPOL has been updated by amendments through the years (http://www.imo.org/).

human consumption do not exceed levels established by Community legislation or other relevant standards (Table 8). For threshold values the MSFD refers to Regulation (EC) No 1881/2006 (see Table 6 for the threshold values).

Table 8 Criteria, including criteria elements, and methodological standards under Descriptor 9 Contaminants in fish and other seafood for human consumption do not exceed levels established by Union legislation or other relevant standards. Relevant pressure: Input of hazardous substances (EC, 2017b).

Criteria elements	**Criteria**	**Methodological standards**
Contaminants listed in Regulation (EC) No 1881/2006. For the purpose of this Decision, Member States may decide not to consider contaminants from Regulation (EC) No 1881/2006 where justified on the basis of risk assessment. Member States may assess additional contaminants that are not included in Regulation (EC) No 1881/2006. Member States shall establish a list of those additional contaminants through regional or subregional cooperation. Member States shall establish the list of species and relevant tissues to be assessed, according to the conditions laid down under 'specifications'. They may cooperate at regional or subregional level to establish that list of species and relevant tissues.	D9C1-Primary: The level of contaminants in edible tissues (muscle, liver, roe, flesh or other soft parts, as appropriate) of seafood (including fish, crustaceans, molluscs, echinoderms, seaweed and other marine plants) caught or harvested in the wild (excluding fin-fish from mariculture) does not exceed: (a) For contaminants listed in Regulation (EC) No 1881/2006, the maximum levels laid down in that Regulation, which are the threshold values for the purpose of this Decision; (b) For additional contaminants, not listed in Regulation (EC) 1881/2006, threshold values, which Member States shall establish through regional or subregional cooperation.	*Scale of assessment:* The catch or production area in accordance with Artuicle 38 of Regulation (EU) No 1379/2013 of the European Parliament and of the Council ([1]). *Use of criteria:* The extent to which good environmental status has been achieved shall be expressed for each area assessed as follows: - for each contaminant, its concentration in seafood, the matrix used (species and tissue), whether the threshold values set have been achieved, and the proportion of contaminants assessed which have achieved their threshold values.
(1) Regulation (EU) No 1379/2013 of the European Parliament and the Council of 11 December 2013 on the common organisation of the market in fishery and aquaculture products, amending Council Regulations (EC) No 1184/2006 and (EC) No 1124/2009 and repealing Council Regulation (EC) No 204/2000 (O) L 354, 28.12.2013, p.1).		

4.2 Multi-use risks for aquaculture products

A main issue surrounding siting an aquaculture facility in an urban area such as a port is the anthropogenic sources of contaminants that may impact the performance of the facility (Goudey & Moran, 2005). In general, moving into offshore environments, which is likely to increase the distance from most pollution sources and to increase water flow, will be beneficial in mitigating food safety concerns (Gentry *et al.*, 2016). However, the combination of aquaculture at floating islands constructions with other use options, introduces nearby pollution sources posing a potential threat to food safety.

For each use option, *i.e.* application of the floating islands, all possible discharges to sea should be considered for its potential of contaminating aquaculture products (see section 4.1). Specific discharges per use option (ports (ships), living / accommodation for workers and energy hub) are addressed in the following sub-sections.

4.2.1 Logistics and transport

In general, port pollution is related to ships, cargo, port facilities and the nearby city (Figure 5). For floating island constructions, relevant issues depend on the combination of applications. For example, in case there is no Living@Sea module, city pollution is not relevant. Furthermore, port development will be minimal. Therefore, only ship related pollution, cargo handling, and storage and port maintenance are relevant in the context of this guidance document.

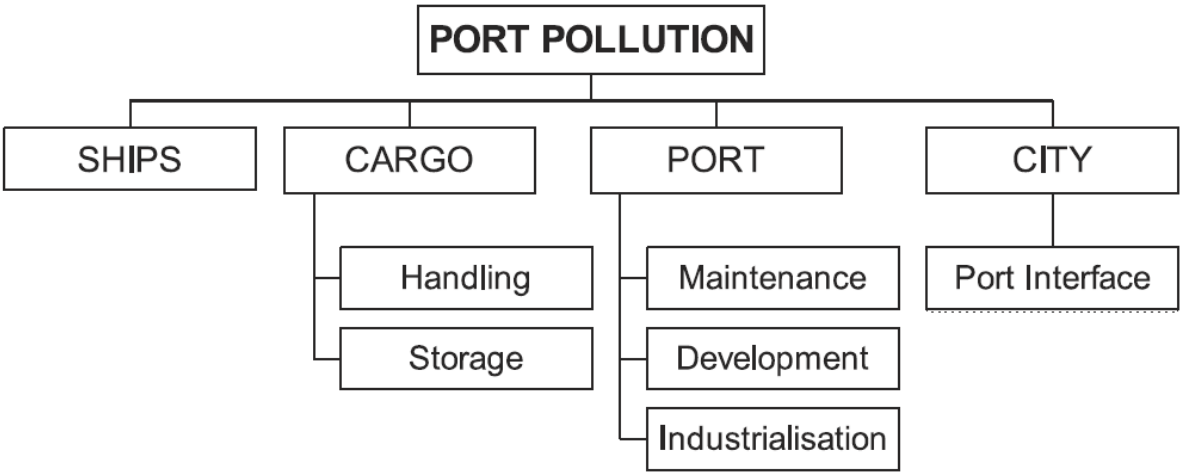

Figure 5 Port pollution and its causes (Goulielmos, 2000).

The following port and ship related discharges should be taken into consideration when combining aquaculture with port facilities:

- Gas Emissions (NO_x, CO_2, SO_x, Soot, Smoke and Particulate Matter).
  Gaseous emissions result from the exhaust gases from diesel fuelled generators for electricity and from combustion engines used for ship transportation. A diesel engine emits e.g. CO_2, NO_x, SO_2 and unburned hydrocarbons (Table 10). Gaseous ship emissions cause an increase in nitrogen and sulfur deposition along shipping routes (Aksoyoglu *et al.*, 2016). Furthermore, conventional outboard motors used in recreational boats discharge their exhaust gases under water which causes a direct emission to the water phase (Table 11). In case such recreational boats visit the floating island constructions, these emissions should be taking into account.
- Ship Waste
  Cargo operations produce wastes such as the remains of bulk cargo storage, rubbish from unpacking, floating garbage and other wastes from daily activities. Garbage (or waste) includes all kinds of food, domestic and operational waste, excluding fresh fish, generated during the normal operation of the vessel and liable to be disposed of continuously or periodically. It is legally regulated by MARPOL 73/78.- Annex V and Directive 2000/59/EC, totally prohibiting the disposal of plastics anywhere in the sea, and severely restricting discharge of other garbage from ships into coastal waters. Disposed waste is a physical hazard for aquaculture (see section 4.1.3) and should thus be prevented at floating island constructions. There are various methods of waste treatment (e.g. waste compressors, plasma technology) that could be implemented and further developed to ensure that waste is not discharged at sea (European Marine Equipment Council, 2010).
- Bilge Water
  Oil/fuel and other chemicals that accumulate as a result of routine operations (*e.g.* from fuel treatment systems) is stored in a settling tank and the water which settles under the layer of oil is pumped overboard via a bilge water treatment system (an oil/water separator). Bilge water is thus a mixture of different substances with varying concentrations. The following substances can be found in bilge water: leaked condensed and coolant water; oil from various sources (lubrication, gear oils, hydro system liquids, etc.); all kinds of fuel (diesel, fuel oil, heavy with different viscosity); dirt and paint particles; corrosion protection agents (European Marine Equipment Council, 2010). Bilge water is allowed to be discharged under conditions (oil content below 15 ppm, the vessel is “en-route”, not mixed with any oil cargo residues nor originate from cargo room bilges (MARPOL Annex I)). Ships moored at floating islands constructions

are, therefore, not allowed to discharge bilge water. For this reason, this potential pollution source is not considered to be of particular concern for aquaculture at floating island constructions.

- Black and grey water
  Black Water is a term used to describe wastewater containing faecal matter and urine (water from toilets). Grey Water is a term generally used to describe water generated from domestic activities such as dishwashing, laundry and bathing. The discharge of black water is regulated by Annex IV of MARPOL 73/78. Grey water is not regulated by MARPOL or any other international regulations. Ship sewage and wastewater contains high levels of BOD, total suspended solids, and coliform bacteria, and typically low pH levels (due to chlorination). The risk of these emissions are also addressed in section 4.1.1.
- Ballast Water
  The ballast water from ships carries marine organisms that have invasive potential (van der Meer I, 2016). Most concern regarding aquaculture and non-indigenous species (NIS) are for the risk of introducing invasive species from aquaculture into the surrounding environment (*e.g.* Copp *et al*., 2016) and not vice versa. This potential pollution source is thus considered not of particular concern for aquaculture at floating island constructions. It should be noted, however, that the potential for NIS to jump from one floating structure to the next has resulted in pontoons being described as hotspots of NIS (Dafforn *et al.*, 2016).
- Underwater Coatings
  Coatings are designed to inhibit organisms attaching and growing on the exterior surface of the ship's hull, and to that end, most coatings release biocides continuously and are an emission source. Most antifoulants use copper as their active ingredient (Table 9). It has toxic effects on various non-target species, such as reduction of growth and reproduction levels in clams, damaging gills of fish and inhibition of phytoplankton growth and it can also contaminate seafloor sediment around farms (Science for Environment Policy, 2015).
- Accidental spills
  Accidental spills are caused by people making mistakes or being careless, equipment breaking down or natural disasters such as hurricanes. Spills can consist of:
    - Oils, lubricants, fuels and other oily liquids. Oil dissolved in the water is quickly dispersed to concentrations below the acute toxicity level, but it can be taken up by organisms and affect their physiology, behaviour, reproductive potential and survival (OSPAR, 2010).
    - Chemicals. Depending on the type of chemical, the spill may dissolve, float, sink or evaporate. The ecological effects of a chemical spill also varies greatly, depending on the chemical properties and spill size.

  A chemical- or oil spill in close proximity to aquaculture facilities could have great impact on the aquaculture products when it reaches the intake water (*i.e.* failure of meeting products standards or even mortality of the cultured plants or animals).
- Noise/vibrations
  Cargo handling equipment and ship traffic are two major sources of noise and vibration, which may cause unacceptable levels of stress among aquaculture animals. Fish and mussels are known to be sensitive to underwater noise (UNEP/CBD, 2012; Carroll *et al.*, 2017). This may affect growth and condition of aquaculture species (Radford & Slater, 2019). There are, however, no risks nor standards for the quality of aquaculture products related to underwater noise. A precautionary approach and optimised system engineering is recommended to reduce the sound impact on culture animals to optimise growth performance (Radford & Slater, 2019).

Table 9 Emissions (kg/year/vessel) by coatings of vessels moored in Dutch ports (seagoing vessels and fishing vessels) and by marine coatings of recreational boats in 2006. Based on data from Netherlands national water board (2008a&b)

Substance	Seagoing vessels	Fishing vessels	Recreational vessels
Copper	0.319	7.075	0.234
Tributylin compounds	0.047	0.000	0.019
Dichlofluanide	0.005	0.152	0.028
Irgarol	0.005	0.152	
Tolylfluanide	0.005	0.152	
Copper thiocyanate	0.005	0.152	
Seanine-211 (kathon)	0.005	0.152	
Zineb	0.005	0.152	0.0005
Zinc pyrithion	0.005	0.152	
Total (PAH 10)			0.05
Diuron			0.005
Triazine			0.005
Ziram			0.0005

Table 10 Emission factors for diesel engines (g/kg diesel oil)

Substance	Emission (g/kg)	Reference
CO_2	3173	(Vreuls & Zijlema 2011)
SO_2	2	(Vreuls & Zijlema 2011)
N_2O	0.02562	(Ministerie van VROM 2010)
CH_4	0.2135	(Ministerie van VROM 2010)

Table 11 Emissions to the water phase by exhaust gases from recreational boats in the Netherlands in 2006 (kg/year). The average emission per boat is estimated by dividing the emission by the number of recreational boats (sailboat; motorboat; speedboat) in that same year: 280240. Based on data from Netherlands national water board (2008b)

Substance	Total emission (kg/yr)	Average emission per boat (kg/yr/boat)
Particulates	20,733	7.4E-02
VOC	1,856,131	6.6E+00
Benzene	24,258	8.7E-02
Toluene	67,496	2.4E-01
1.3-butadiene	34,053	1.2E-01
Formaldehyde	23,382	8.3E-02
Naphthalene	451	1.6E-03
Phenanthrene	34.5	1.2E-04
Anthracene	7.72	2.8E-05
Fluoranthene	8.13	2.9E-05
Chrysene	4.43	1.6E-05
Benzo(a)anthracene	1.98	7.1E-06

Benzo(b)fluoranthene	11.72	4.2E-05
Benzo(k)fluoranthene	1.06	3.8E-06
Indeno(1,2,3-c,d)pyrene	0.06	2.1E-07
Benzo(g,h,i)perylene	0.22	7.9E-07
Benzo(a)pyrene	1.73	6.2E-06
PAH (VROM-10)	511	1.8E-03
PAH (Borneff 6)	12.9	4.6E-05

Recommended water and sediment quality monitoring parameters for port environments are (World Bank Group, 2017):

- Dissolved oxygen
- Temperature
- pH
- Turbidity
- Secchi disk transparency
- Conductivity/Salinity
- Condition of biological communities
- Total suspended solids (TSS)
- Chlorophyll
- Total phosphorus
- Filterable reactive phosphate
- Total nitrogen
- Oxides of nitrogen
- Ammonia
- Toxics: Metals and metalloids; non-metallic organics; organic alcohols; chlorinated alkanes and alkenes; anilines; aromatic hydrocarbons (including phenols and xylenols); organic sulphur compounds; phthalates; organochlorine and organophosphorus pesticides; herbicides and fungicides
- Sediment (metals and metalloids; organometallics; organics)
- Other site-specific parameters, as relevant

Further guidance on environmental impacts from port activities is provided by e.g. IAHP (1989); The International Bank for Reconstruction and Development/World Bank (1990); and PIANC (2014).

4.2.2 Accommodation for workers and living

The risk of using the floating island constructions as living / accommodation for workers in combination with aquaculture may be related to the discharge of domestic waste water (black and grey water, see section 4.2.1). Although it is the intention to re-use and re-cycle or generate bio-fuels from waste streams on the floating islands, we consider these waste streams as potential sources of pollution. Based on the average amount of waste water generated by accommodations at offshore mining platforms (Jak & Schobben, 1995), the average amount of wastewater per person is estimated at 35 m^3/yr. The composition of typical domestic/municipal wastewater is shown in Table 12 and Table 13. Table 14 provides typical concentrations of microorganisms in domestic wastewater. Wastewater may also contain specific pollutants Table 15).

Table 12 Constituents present in domestic wastewater and their possible consequences (Henze & Comeau, 2008).

Wastewater constituents		
Microorganisms	Pelagic bacteria, virus and worm eggs	Risk when bathing and eating shellfish
Biodegradable organic materials	Oxygen depletion in rivers, lakes and fjords	Fish death, odours
Other organic materials	Detergents, pesticides, fat, oil and grease, colouring, solvents, phenols, cyanide	Toxic effect, aesthetic inconveniences, bio accumulation in the food chain
Nutrients	Nitrogen, phosphorus, ammonium	Eutrophication, oxygen depletion, toxic effect
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic effect, bioaccumulation
Other inorganic materials	Acids, for example hydrogen sulphide, bases	Corrosion, toxic effect
Thermal effects	Hot water	Changing living conditions for flora and fauna
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences, toxic effect
Radioactivity		Toxic effect, accumulation

Table 13 Typical composition of raw municipal wastewater with minor contributions of industrial wastewater (in g/m^3) (Henze & Comeau, 2008). High represents concentrated wastewater (i.e. low water consumption) and low represents diluted wastewater (i.e. high water consumption). chemical oxygen demand (COD), biological oxygen demand (BOD), volatile fatty acids (VFA), nitrogen (N), phosphorus (P) total suspended solids (TSS), volatile suspended solids (VSS).

Parameter	**High**	**Medium**	**Low**
COD total	1,200	750	500
COD soluble	480	300	200
COD suspended	720	450	300
BOD	560	350	230
VFA (as acetate)	80	30	10
N total	100	60	30
Ammonia-N	75	45	20
P total	25	15	6
Ortho-P		15	10
TSS	600	400	200
VSS	480	320	200

Table 14 Concentrations of microorganisms in wastewater (number of microorganisms per 100 ml) (Henze & Comeau, 2008).

Micro organisms	High	Low
E. coli	5.10^8	10^6
Coliforms	10^{13}	10^{11}
Cl. perfringens	5.10^4	10^3
Fecal *Streptococcae*	10^8	10^6
Salmonella	300	50
Campylobacter	10^5	5.10^3
Listeria	10^4	5.10^2
Staphylococcus aureus	10^5	5.10^3
Coliphages	5.10^5	10^4
Giarda	10^3	10^2
Roundworms	20	5
Enterovirus	10^4	10^3
Rotavirus	100	20

Table 15 Some specific organic and synthetic pollutants (left) and metals (right) in raw municipal wastewater with minor contributions of industrial wastewater (in g/m^3) (Henze & Comeau, 2008). High represents concentrated wastewater (i.e. low water consumption) and low represents diluted wastewater (i.e. high water consumption). Di(2-ethylhexyl)phthalate) (DEHP), nonylphenol ethoxylates (NPE), Polycyclic Aromatic Hydrocarbons (PAH), Linear Alkylbenzene Sulfonates (LAS)

Parameter	High	Median	Low
Phenol	0.1	0.05	0.02
Phthalates, DEHP	0.3	0.2	0.1
Nonylphenols, NPE	0.08	0.05	0.01
PAHs	2.5	1.5	0.5
Methylene chloride	0.05	0.03	0.01
LAS	10,000	6,000	3,000
Chloroform	0.01	0.05	0.01

Metal	High	Medium	Low
Aluminium	1,000	600	350
Cadmium	4	2	1
Chromium	40	24	10
Copper	100	70	30
Lead	80	60	25
Mercury	3	2	1
Nickel	40	25	10
Silver	10	7	3
Zinc	300	200	100

4.2.3 Energy hub

The use of floating island constructions as an 'energy hub' could involve the following:

- The floating island constructions may be provided with energy converters to harvest the relative motion between the outer ring of modules. There are no emissions from this type of renewable energy production during normal operation. However, hydraulic oil is used for the converters which could be released into the aquatic environment in case of damage to the constructions or technical failures. Oil dissolved in the water is quickly dispersed to concentrations below the acute toxicity level, but it can be taken up by organisms and affect their physiology, behaviour, reproductive potential and survival (OSPAR, 2010). In case such a spill reaches the aquaculture site, it could cause mortality among the culture or cause failure of meeting product standards as a result of accumulation of spilled substances in the body tissue of cultured organisms.
- The floating island constructions may be provided with an electrochemical storage system (rechargeable batteries) in combination with super-capacitors. There are no emissions expected during normal operation. However, in case the energy storage system requires heating, ventilation, and/or air conditioning this could be a source of noise emission. The emission of noise may affect growth and condition of aquaculture animals (Radford & Slater, 2019). Furthermore, in case of a major accident resulting in sinking of the construction the energy system could end up in the aquatic environment releasing the chemicals used for electricity storage. Chemicals used for batteries are e.g. sodium sulfur, lead oxide or lead acid, and lithium iron phosphate. In case such chemicals reach the aquaculture site, it could cause mortality among the culture or cause failure of meeting product standards.
- Living quarters for workers, see 4.2.2.

4.3 Prevention and mitigation

In this section some mitigation and prevention options are provided which could be considered for the various use options, in order to maintain good water quality for aquaculture. Suggestions for general prevention and mitigation measures are described in chapter 2.3.

- Water quality control and treatment:
  Examples of aquaculture combined with other human activities are known, such as systems exploiting industrial by-products, in particular thermal effluents (Bunting & Little, 2005). Water pre-processing systems are key factors in the success of urban area aquaculture. Facilities must take more precautions to assure water intake has acceptable water-quality levels for its housed activities. Depending on the sensitivity of the species chosen and the level of pollution, additional filtration, such as carbon filters and high exposure levels of UV, could be necessary. Additional filtration will aid in removing heavy metals and potential viruses, parasites and bacteria (Goudey & Moran, 2005).
- Clean-up of floating wastes:
  Periodical clean-up of floating wastes is also necessary for preservation of water quality and subsequently protection of aquaculture conditions.
- Oil spill detection and treatment:
  Detection of spills is also important for safeguarding of aquaculture products. Since accidental spills are unavoidable, recovery vessels, oil fences, and other oil spill treatment options should be prepared with a view to minimizing contamination. A contingency plan is important to prevent contamination of aquaculture products in case of an accidental spill. Such a plan should be consistent with the IMO Manual on Oil Pollution Section II—Contingency Planning (IMO, 2018).
- Positioning of aquaculture facilities:
  Separation of aquaculture from a port area and other potential contamination sources could be an effective means to minimise risks from operational and accidental discharges. This could be implemented by taking into account prevailing wind and current directions as well as construction of physical barriers.

- Optimised design to reduce sound impact:
  A precautionary approach and optimised system engineering is recommended to reduce the sound impact on culture animals to optimise growth performance (Radford & Slater, 2019).
- Regulations on ship discharges and provision of reception facilities:
  Appropriate regulations on ship discharges and provision of reception facilities are required for control of emissions and effluents from ships. Port operators should provide collection, storage, and transfer and/or treatment services, and facilities of sufficient capacity and type for all wastewater generated by vessels at the port in accordance with MARPOL[3] and national regulations.
- Domestic waste water treatment:
  Black and grey water treatment systems (e.g. membrane bioreactors, vacuum toilets) could be installed in order to purify the water discharged into the sea.

4.4 References

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[3] Ports are requested to provide sufficient reception facilities to receive residues and oily mixtures generated from ship operations according to provisions of the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL, 1973) as amended by the 1978 Protocol (MARPOL, 1973/78). Besides oily residues, reception of sewage and garbage is also required in accordance with the needs of calling ships. Connection to sanitary treatment facilities or a municipal waste treatment system may be a means for a port to receive such wastes.

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5. Ecosystem interactions

Interactions with the environment include the impact of operations on the marine ecosystem, as well as the environmental provisions (*e.g.* nutrients for seaweed culture) and the impacts of the marine environment on structures (*e.g.* salinity, fouling organisms).

5.1 Impact of operations on the marine ecosystem

The floating island constructions change the type of resources available for the resident organisms, for example by increasing the proportion of sheltered, shaded, vertical and floating surfaces (Table 16). Orientation (e.g. vertical vs horizontal surfaces), slope and the surface texture of construction materials also affect the colonisation of marine organisms (Dafforn *et al*., 2016).

Floating island constructions are also potentially linked to a variety of pollution sources, depending on their use options (Table 16 and Chapter 4.2). This includes changes in light, collision risk, non-indigenous species, noise and/or contamination associated with aquaculture, port/boating activity, accommodation/housing and energy hub. These pressures may have consequences for behaviour and mortality of marine organisms such as birds, mammals and fish (EC, 2008; 2017).

Table 16 The physico-chemical differences between natural and urban structures and the associated ecological consequences (Dafforn et al.*, 2016).*

Physico-chemical characteristics	Ecological consequences
Human-made substratum	Foreign materials result in different ecological communities.
Low structural complexity/heterogeneity	Reduced native diversity because of fewer microhabitats and refuges.
Orientation and slope	Favours invertebrates over algae and often non-indigenous species
Low light	Inhibits native algal assemblages and favours non-indigenous invertebrates
Reduced connectivity to benthos	Less accessible to key benthic consumers
Increased resource (space) availability	‘Blank slate’ favours opportunistic species such as non-indigenous species
Movement	Floating structures are analogous to boat hulls and provide stepping stones for invasive species
Pollution	Increased contamination and artificial light due to boating activities. Alterations in flow resulting in increased retention of fine sediments, contaminant inputs and the likelihood of low oxygen environments.

Non-indigenous species

These structural changes, among others, such as shading and movement, are some of the reasons that urban structures support different assemblages to those found in natural reef habitats and may facilitate non- indigenous species (NIS). The addition of hard substrata on the marine environment by the construction of structures can also serve as ‘stepping stones’, facilitating the spread and establishment of NIS, increasing their numbers. The physical design of artificial structures has, therefore, major consequences on the composition of ecological communities (Daffron *et al*., 2016).

Light

Artificial lighting is required for safety navigation and illumination of accommodation/work areas. The offshore emission of light could affect marine life, such as the composition of invertebrate communities and fish abundance (McConnell *et al*., 2010; Davies *et al*., 2015) and attraction of birds (Wiese *et al.*, 2001).

Another change in light conditions is related to the floating structure itself, blocking the underlying water column from sunlight (shading). Innovations to mitigate shading of light are known for coastal structures, which included the creation of boardwalk windows and “skylights” designed to maximize light penetration beneath the structure (Dafforn *et al*., 2016).

There are several operations connected with floating island structures: energy hub (WP6), living (WP7). aquaculture (WP8), ports (WP9). These operations can also have impacts on the marine environment. It is very time-consuming to carry out in-depth assessments including quantification of this impact. Recently, deliverables from two EU-project dealt with the environmental impacts of activities at artificial islands: MERMAID D4.7 and TROPOS D6.2.

The 5 above mentioned structures and activities connected with floating island constructions may affect many habitat types and species. In addition other human activities may be present in the vicinity of the floating island structures, also affecting the same marine environmental components. In order to cope with a broad spectrum of impact chains exerted by human activities, a general approach is recently developed for integral state assessments to identify and prioritise: integral cumulative effect analysis (iCEA). Impact chain relations are based on the Driver-Pressure-State-Impact-Response (DPSIR) concept in which each impact chain consists of D (driver) - P (pressure) – S (state). Examples of an iCEA for human activities in marine and/or freshwater ecosystems, including aquaculture, ports and shipping in the North Sea, are ODEMM (Knights *et al.*, 2015) and AQUACROSS (Borgwardt *et al.*, 2019). These iCEA studies used the pressure types of the MSFD with some additional pressure types.

Table 17 shows the pressure types which were included by Borgwardt *et al.* (2019). Many pressure types are involved but some will be of minor importance considering the potential impact risk. Floating island structures, energy hub, and human living on these artificial structures, were not assessed. Borgwardt *et al.* (2019) also quantified the impact risk of these impact chains, but these values are not very useful for current project because the activities and the locations of the floating island structures are too specific.

Table 17 The relevance of pressures of floating island structures and associated facilities and activities. Based on the pressure assessment of human structures and activities at sea by Borgwardt et al., (2019) in combination with own expert judgement for the special conditions

Descriptors/Pressures	Island structures	Energy hub (WP6)	Living (WP7)	Aquaculture (WP8)	Transport and logistics (WP9)
Abrasion/Damage		✓		✓	
Artificialisation of habitat	✓	✓		✓	✓
Barrier to species movement		✓			
Change of habitat structure/morphology	✓	✓		✓	✓
Changes in input of organic matter			✓	✓	
Changes in Siltation				✓	
Changes in wave exposure		✓			
Death or Injury by Collision	✓	✓		✓	✓
Disturbance (visual) of species	✓	✓	✓	✓	✓
Electromagnetic changes		✓			
Emergence Regime Changes					
Extraction of flora and/or fauna				✓	
Input of light	✓		✓		✓
Introduction of genetically modified species					
Introduction of Microbial pathogens			✓	✓	
Introduction of non-indigenous species				✓	✓
Introduction of Non-synthetic compounds	✓	✓	✓	✓	✓
Introduction of Radionuclides					

Descriptors/Pressures	Island structures	Energy hub (WP6)	Living (WP7)	Aquaculture (WP8)	Transport and logistics (WP9)
Introduction of Synthetic compounds	✓	✓	✓	✓	✓
Litter	✓		✓	✓	✓
N&P Enrichment			✓	✓	
Noise (Underwater and Other)	✓	✓	✓	✓	✓
pH changes					
Salinity changes					
Selective Extraction of non-living resources: substrate e.g. gravel					
Smothering		✓		✓	
Thermal changes			✓		
Total Habitat Loss		✓			
Translocations of species (native or non-native)	✓			✓	✓
Water abstraction					
Water flow rate changes		✓	✓		✓

Aquaculture was treated in those iCEA as one sector because for this sector, as well as for many other sectors, it was chosen to aggregate primary activities in a limited number of sectors, in order to be able to compose a balanced set of sectors for the North Sea. However, aquaculture at sea is a very diverse sector, comprising finfish culture, shellfish culture, and macro-algae (seaweed) culture. The characteristics and the extent of the pressures and the potential impact on the environment of these culture types differ considerably. It is, therefore, recommended to discriminate these three types of aquaculture for future impact assessments. However, we do not discriminate these aquaculture types in order to provide a global overview of the relevant pressures types of aquaculture at sea for this report.

5.2 Ecosystem preconditions for food production at sea

Whereas the preceding paragraph dealt with the impact of activities on the marine environment, this paragraph deals with the effects of the environment on the application of aquaculture. The focus is on the environmental preconditions that should be met in order to allow the culturing of mussels, seaweeds and fish.

5.2.1 Mussel culture

Floating island constructions can be used for suspended culture of mussels. The construction can be used as attachment point for culture ropes. In addition, it can function as a processing platform where the mussels are graded and packed. A large number of feasibility studies have been carried out for offshore culture of mussels (Kamermans & Verdegem 2004; Kamermans *et al*. 2011, 2016; Steenbergen *et al*. 2005; Lagerveld *et al*. 2014; Jansen *et al*. 2016; Van den Burg *et al*. 2017).

Growth rates in *Mytilus* spp. are highly variable and the majority of variation is probably environmentally determined depending on (at least) the following factors (Tyler-Walters, 2008):

- temperature;
- salinity;
- food availability;
- tidal exposure;
- intraspecific competition for space and food, and
- parasitism.

For example, in optimal conditions *Mytilus edulis* can grow to 60 -80 mm in length within 2 years but in less suitable conditions mussels may take 15 -20 years to reach 20 -30 mm in length (Tyler-Walters, 2008).

Preconditions for offshore culture of mussels are presented in Table 18. Although temperature is an important growth condition (Tyler-Walters, 2008), in temperate environments such as the North Sea this was found not to be limiting for offshore culture. Intraspecific competition for space and food, as well as parasitism are also important and should be kept under control by aquaculture design and operations. Specific sensitivities of *Mytulis edulis* to physical, chemical and biological pressures are provided by the Marine Life Information Network (www.marlin.ac.uk). Good water quality is required for mussel culture. Mussels are known to accumulate contaminants, such as metals and PAHs. High contaminant concentrations in mussels have been found especially in the neighbourhood of (small) harbours (Bergman, 1993). In addition, bivalves are known to be sensitive to underwater noise (UNEP/CBD, 2012; Carroll *et al*., 2017). Exposure to stressful levels may affect growth and condition.

Table 18 Preconditions for offshore culture of mussels (based on tolerance/optimum ranges reported by Tyler-Walters (2008) and Van den Bogaart et al. *(2019)).*

Parameter	Non/less suitable	Suitable/optimal
Temperature	<10 or > 20°C	10-20°C
Salinity	<25 psu	> 25 psu
Current velocity	<0.514 m/s	>0.514 m/s
Chlorofyl-a (food availability)	0.5-2 resp. 30-104 µg/l	2-30 µg/l
SPM (Suspended Particulate Matter)	<10 or >90 mg/l	10-90 mg/l

5.2.2 Seaweed culture

Several seaweed species can potentially be cultured offshore for use as food, feed and/or fertiliser. Preconditions for offshore culture of seaweed are presented in Table 19.

Table 19 Preconditions for offshore culture of seaweed (based on tolerance/optimum ranges reported by Van den Bogaart et al.*, 2019).*

Parameter	Non/less suitable	Suitable/optimal
Temperature	<5 or > 15ºC	5 - 15 ºC
Salinity	<20->35 psu	20-35 psu
Depth	>20 m	<20 m
Current velocity	Low	Medium to strong
N-content	<10 µmol/l	10-40 µmol/l
N-flux	<20 µmol/m^2/s	20-30/>30 µmol/m^2/s
P-content	<0.3 µmol/l	>0.3 µmol/l
P-flux	<1.0 µmol/m^2/s	Max. 1.0-1.5 µmol/m^2/s

Five seaweed species (*Fucus vesiculosus, Palmaria palmate, Ascophyllum nodosum, Saccharina latissima* and *Laminaria digitate*), which have been reviewed by Van den Bogaart *et al.* (2019) for their potential to be cultured offshore in the North Sea, are briefly described below. Specific sensitivities of these species for physical, chemical and biological pressures are provided by the Marine Life Information Network (www.marlin.ac.uk).

Fucus vesiculosus, known by common names such as bladder wrack, black tang, or rockweed, is considered a potential species for offshore seaweed culture due to its wide distribution and ability to adapt to different conditions (Van den Bogaart *et al*., 2019). It is a large brown algae, that can be found in high densities and has a life-span of about 4-5 years. The fronds have been known to grow up to 2 m under sheltered conditions (White, 2008). It is known to have many uses including food, feed, fertilizer, bodycare products (such as shower gels and body creams), and health supplements (kelp tablets) (White, 2008; Van den Bogaart *et al*., 2019).

Another potential species for offshore seaweed culture is *Palmaria palmate*, known by common names such as Dulse, or Dillisk (Hill, 2008b). It is a foliose red algae with a tough flat frond, usually between 20 and 50 cm in length, but sometimes up to 1 m. The algae grows directly from a small discoid holdfast gradually widening and subdividing and has a dark red colour, with purple tints under water. Although growth and harvest are thought to be positive offshore, the location is important because the species requires moderate to high current velocities (Van den Bogaart *et al*., 2019). It is used for feed and (health)food (Van den Bogaart *et al*., 2019).

Ascophyllum nodosum, known by common names such as Yellow Tang, or Knotted wrack, is a common large brown seaweed, dominant on sheltered rocky shores (Hill & White, 2008). The species has long strap like fronds with large egg-shaped air bladders at regular intervals. The fronds of *Ascophyllum nodosum* are typically between 0.5 and 2 m in length. The species grows slowly and plants can live to be several decades old. Individual fronds can become up to 15 years old before breakage (Hill & White, 2008). *Ascophyllum nodosum* is harvested in Ireland, Scotland, Europe, Canada and the north-west Atlantic (Hill & White, 2008). The potential for offshore culture of *Ascophyllum nodosum* is unknown and should be investigated (Van den Bogaart *et al*., 2019). It is used in alginates, fertilisers and for the manufacture of seaweed meal for animal and human consumption (Hill & White, 2008; Van den Bogaart *et al*., 2019).

Saccharina latissima, known by common names such as Sweet Kelp, Kombu Royale, or Sugar Kelp, is a large brown kelp, which lives for 2 to 4 years and grows quickly from winter to April. It is yellowish-brown in colour and can grow up to 4 m long (White & Marshall, 2007). The potential to develop large scale sustainable offshore cultivation in the Dutch North Sea has been investigated and was shown to be promising but complex (Jansen *et al*., 2019). *Saccharina latissima* is used for consumption (may be eaten as a sea vegetable) and for alginate extraction (White & Marshall, 2007; Van den Bogaart *et al*., 2019).

Laminaria digitata, known by the common name Oarweed, is a large conspicuous kelp growing up to 2 m in length and is commonly found at low water during spring tides on rocky shores. It is glossy and dark brown in colour (Hill, 2008a). It is used for consumption and extracts (Van den Bogaart *et al*., 2019).

5.2.3 Fish culture

For eight fish species which are presently cultivated in European seas, the optimum range (between the minimum and maximum limits) are provided (Table 20). Based on these optimum ranges, suitability maps were developed by Davasuuren *et al*. (2013), showing three levels of suitability:

1. highly suitable areas, where cultivation of a given species is possible, because the main environmental conditions are within the optimum range (between the minimum and maximum limits)
2. moderately suitable areas, where some factors are not within the species' optimum levels, but only within its tolerable range; and
3. not suitable areas, where a modification of environmental conditions is needed, *e.g.* to provide higher chlorophyll concentration, increase water temperature and/or to ensure a sufficient supply of oxygen.

Suitability maps showing which areas (marine ecosystems) are suitable for aquaculture activities for eight fish species (*Coregonus lavaretus, Dicentrarchus labrax, Diplodus sargus, Gadus morhua, Oncorhynchus mykiss, Salmo salar, Solea senegalensis* and *Sparus aurata*) can be found in Davasuuren *et al.* (2013).

Table 20 Optimum minimum and maximum limits for fish species cultivation (Davasuuren et al.*, 2013)*

Scientific name	Common name	Case study area	Water salinity ‰		Temperature (degrees °C)		Depth (meters)		Wind m/sec	Wave height m	Chlorophyll mg/l		Dissolved oxygen mg/l		Sediment type
			Min	Max	Min	Max	Min	Max			Min	Max	Min	Max	
Coregonus lavaretus	European whitefish	Baltic Sea	5.7	8.9	9	18	10	50	7.3	1.5	5	10	5	10	Except fine sediments
Dicentrarchus labrax	European seabass	Algarve Coast	3	38	9	17	12	100	10	0.0	4	8	2.5	5.7	Various kind
Diplodus sargus	White seabream	Algarve Coast	28	38	14	25	10	150	10	0.0	5	17	2.5	5.7	Hard substrate, sand
Gadus morhua	Atlantic cod	Hardangerfjord	28	35	5	18	10	150	10	1.4	1.0	2.1	5	25	Except mud
Oncorhynchus mykiss	Rainbow trout	Baltic Sea	0.0	26	9	14	10	50	8.1	1.9	3.6	7.5	5	13	Mixed sediments
Salmo salar	Atlantic salmon	Hardangerfjord	30	34	7	20	10	150	7.8	5	2.5	20	0.77	10	Not suspended
Solea senegalensis	Senegalese sole	Algarve Coast	33	35	13	22	12	65	6.8	0.7	6	14	5	25	Mixed sediments
Sparus aurata	Gilt-head sea bream	Algarve Coast	15	35	18	26	10	150	7	0.6	0.6	2.4	6	25	Mixed sediments

Within the context of Space@Sea, three fish species are considered for aquaculture: Atlantic salmon (*Salmo salar*), Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrachus labrax*). Species specific recommendations addressing fish welfare are provided by the Fish Ethology Database (www.fishethobase.net; Volstorf 2019a,b,c) and are summarised in Table 21.

Table 21 Summary of recommendations addressing fish welfare in aquaculture (based on information from Volstorf 2019a,b,c)

Aspect	Atlantic salmon	Gilthead seabream	European seabass
General			
Escapes	Rear only in environments where it naturally occurs and prevent escapes. Escapees from fish farms have negative or at most unpredictable influences on the local ecosystem		
Other aspects	Do not rear individuals past the parr stage. Address inter-individual differences in habitat use	Take measures against spawning into the wild.	Take measures against spawning into the wild.
Designing the (artificial) habitat			
Substrate preference	No clear substrate preference.		
Most natural solution for substrate	Provide a range of rock sizes from gravel to boulder	Provide seagrass, gravel, and sand; alternatively, provide glass gravel in	Provide sand as well as mud and different kinds of vegetation

Aspect	Atlantic salmon	Gilthead seabream	European seabass
		blue or red-brown with which juveniles displayed lower aggression than with green or no glass gravel.	
Shelter	Provide shelter	Provide enough sand to allow for burrowing; or provide artificial shelters	-
Cover	Avoid complete cover in respect for the diurnal rhythm		
Vegetation	Avoid dense vegetation or moving elements	-	-
Safety measures	Provide access to the water surface, ensure safety measures to avoid individuals jumping out of the holding system	-	Ensure safety measures to avoid individuals jumping out of the holding system
Natural photoperiod	8-18 hours	8-16 hours	8-18 hours
Light intensity	Provide low light intensity and avoid light with high intensity (>0.82 µmol/m2/s and abrupt changes	For better growth in juveniles, provide 200 lux than 80 lux	-
Light colour	-	Avoid red light, as it decreases growth and might induce stress	-
Resting period	Diurnal rhythm, resting period at night or in the dark		
Water parameters			
Temperature preference	No clear temperature preference		
Best probable temperature	12-20 °C, eggs not warmer than 16 °C.	11-30 °C, larvae at 16-22 °C.	18-26 °C.
Water velocity	no clear velocity preference. Provide variations in the direction and the velocity of the water inlet preferably between 4 and 50 cm/s	-	no clear velocity preference. Provide variations in the direction and the velocity of the water inlet preferably between 0 and 200+ cm/min.
Oxygen	provide eggs with oxygen concentrations ≥7 mg/L at an incubation temperature of 12.5 °C and water velocity ≥100 cm/h	-	in the wild, oxygen level is at 4.5-12 mg/L.
Migration type	Anadromous	Amphidromous	Amphidromous
Natural salinity	Freshwater level from egg to parr stage (and again as grilse) and seawater level at smolt stage	Seawater level at hatching and oscillates between seawater level in winter and brackish water the rest of the year from fry to adult stage. Keep fry at salinities of 18-28‰ for best growth.	Fresh or brackish water level from post-larvae to juvenile stage and seawater level at juvenile and adult stage
pH	In the wild, pH is at 6.8-7.9. For all freshwater stages, keep pH at ≥5.4	-	-
Swimming space (distance, depth)			
Distance	Provide at least 60+ m	Provide enough space	
Depth	Provide at least 0.05-3+	Provide at least 3-5 m,	Provide at least 3-5 m,

Aspect	Atlantic salmon	Gilthead seabream	European seabass
	m	ideally up to 30 m	ideally up to 73 m
Flight	Provide enough depth for the flight response		-
Temperature layers	Providing enough space for individuals migrating to layers with preferred temperatures		
Feeding			
Trophic level	Carnivorous trophic level 4.5.	Mainly carnivorous, trophic level 3.7	Carnivorous, trophic level 3-4.6
Alternative species	Consider alternative species without or less fish meal/oil in order not to contribute to overfishing		
Protein substitution	Try to substitute protein feed components in order not to contribute to overfishing		
Feed delivery	Refrain from feeding during night time		
Food competition	Food competition results in variable growth rates		with self-feeders, there is no food competition
Growth	In the wild, matures at 2-5 years	In the wild, matures in the first or second year.	In the wild, matures at 5-7 years.
Reproduction			
Nest building	Female builds nest that is called redd, gravel breeder; provide gravel, water velocity of 0.2-1.1 m/s, 5-76 cm water depth	Sea spawner	
Natural spawning season and conditions	Autumn to winter in fresh water	Autumn to spring in seawater.	Winter to spring at temperatures of 10-15 °C at 14-35 ppt.
Fecundity	Average one redd with 20-450 eggs per female	4,100-80,000 eggs daily per female for 4-100 days.	293,000-258,000 eggs per kg body weight.
Stocking density			
Maximum	The business plan should be calculated on the basis of a maximum stocking density that will never exceed the tolerable maximum with regard to fish welfare		
Stocking juveniles and adults	keep at <22 kg/m3, preferably even <10 kg/m3	keep at <22 kg/m3.	keep at <20 kg/m3, preferably even <10 kg/m3
Restriction	Consider loss of space due to structures inside and outside the system and calculate density accordingly		
Environmental conditions	Consider increased density at places with preferential conditions and calculate density accordingly		
Aggregation	Consider increased density at places due to formation of schools and calculate density accordingly.		
Aggression	Aggression may entail displays, attacks, displacements, chases, nips, choose density given displayed aggression		-
Territoriality	In the wild, territorial. Consider space loss due to territoriality and calculate density accordingly.	-	-
Occupation			
Substrate to search for food	In size of gravel to boulder	Sand, rocks, or gravel and seagrass	Sand or mud
Challenges	If after decreasing stress and providing everything welfare assuring, you still notice stereotypical behaviour, vacuum activities, sadness, then provide mental challenges, diversion, variety, and check reactions.		
Handling			
Handling	Handle with care and high efficiency		
Abnormal behaviour	Check for behaviour deviating from the norm		
Stress reduction	Avoid certain sounds like	Avoid sounds of 0.1-1	-

Aspect	Atlantic salmon	Gilthead seabream	European seabass
	infrasound of 12.5 Hertz or slapping noise on the water surface	kHz or, if inevitable, play offshore sounds to reduce stress or music to stimulate growth.	
Directing individuals (e.g., for cleaning purposes)	Make use of Atlantic salmon's ability to be conditionable to reduce stress	Use acoustic stimuli	Make use of European seabass' ability to be conditionable to reduce stress
Cage submergence	Consider cage submergence against detrimental surface conditions or infestation with sea lice as a stress-free alternative to other methods	-	Consider cage submergence against detrimental surface and weather conditions and because it is less stressful than rearing in surface cages
Confinement	Avoid confinement, as it causes stress		
Crowding	Avoid crowding, as it causes stress	-	Avoid crowding, as it causes stress
Disturbance	Keep disturbances (e.g. passing by, leaning over, cleaning) to a minimum (or restrict view to areas where disturbances could occur), as they might cause stress	-	-
Slaughter			
Stunning rules	Render individuals unconscious as fast as possible and make sure stunning worked and they cannot recover		
Stunning methods	Prefer percussive stunning		Prefer electrical stunning
Slaughter methods	Bleed or gut individuals immediately after stunning, i.e. while unconscious		
Certification			
Certification	Follow one of the established certification schemes in aquaculture in order to improve the sustainability of aquafarming		

5.3 Ecosystem impacts on floating structures

The proposed construction of the floating modules is made out of reinforced concrete (Memo Adams & Kalofotias, 10/05/2019). Considering a lifetime of 50 years, reinforced concrete is expected to have higher survivability then steel, and is not susceptible to fatigue. Al over the world, there are about 350 offshore gravity and floating concrete constructions in operation.

Two types of environmental impacts related to the life-time and behavior of offshore platforms are relevant to consider:

- Reinforcement corrosion.
- Fouling organisms.

5.3.1 Corrosion and damage to reinforced concrete

The steel reinforcement used in concrete is susceptible to corrosion, resulting in loss of steel area, loss of bond, expansion of the reinforcement volume leading to cracking and spalling of concrete (reviewed by Dauji, 2018). Especially concrete constructions exposed to tidal fluctuations, or to the action of waves and currents. are affected. These factors also apply to the floating constructions being developed within Space@Sea.

The impact of chloride on the steel used for the reinforcement of concrete causes damage to the reinforced concrete. Factors of influence upon the corrosion of steel in the marine environment are humidity, temperature and salt (chloride). Weathering of the concrete, small cracks and diffusivity of the concrete may allow chloride, and also sulfates to reach the steel reinforcement and initiate corrosion. Therefore, the exposure to harsh maritime conditions, including waves, salt intrusions, shocks, collisions, heath and freezing may increase the risk of corrosion.

Chloride intrusion, causing corrosion, may be controlled in different ways (Dauji, 2018). Several preventive measures can be taken by the selection of materials and its processing:

- use of good quality (dense) concrete, achieve by good mixing, combination of materials and use of additives (*e.g.* microsilica);
- use of coating on the surface of concrete;
- use of coated reinforcement;
- use of alternatives to carbon steel for reinforcement (e.g. stainless steel, galvanized steel, and fibers);
- use of cathodic protection.

In order to minimize impacts on the structure, mitigating measures can be taken:

- set up strategies for periodic inspection and maintenance;
- covering of cracks in the concrete.

It is evident that for the design of modular floating islands these factors need to be taken into account.

5.3.2 Fouling

Organisms attached to concrete structures, referred to as marine growth or fouling, may either protect or increase deterioration of their substrate.

Urban structures in the marine environment represent major habitats for marine organisms. The species composition and abundance on such structures depends on factors such as:

- Composition of the substrate (natural sandstone, concrete, metal). Ecologically friendly materials (*e.g.* ECOncrete®) are available, that not only improve performance and durability, but also reduce ecological stress and encourage the development of natural communities (Dafforn *et al.*, 2016). The abundance, richness and diversity of invertebrates and fish are higher on and around structures made from a concrete mix with an ecological design compared to 'standard concrete' (composed of Portland based concrete), while the ratio of invasive to local species may be considerably lower (Ido & Shimrit, 2015).
- Type of habitat (e.g. natural reefs, pontoon, pillars). Epibiotic[4] assemblages were found to be strongly affected by the type of habitat (rocky reef vs. pontoon) (Connell, 2000).
- Orientation. Orientation (vertical vs horizontal surfaces) is of great influence on the biological diversity of epibiota on artificial structures (Knott *et al.*, 2004).
- Motion. Hydrodynamic features greatly differ between floating (movable) and fixed (motionless) artificial substrata, which in turn affect the structure of their associated communities (Shimrit *et al.*, 2008). Dominant foulers on static panels in a temperate marine environment were the mussel *Mytilus edulis* (maximum of 7470±2830 individuals dm^{-2}) and the barnacle *Balanus improvisus*. (maximum of 2295±680 individuals dm^{-2}) (Berntsson & Jonsson, 2003).

All infrastructures suffer from degradation and need to be maintained. Sedentary and mobile organisms growing on hard substrates contribute to the deterioration of coastal engineering structures by both enhancing and retarding

[4] Organisms growing attached to a living surface.

weathering and erosion. Barnacles likely reduce rates of mechanical breakdown on concrete by buffering near-surface thermal cycling and reducing salt ion ingress[5] (Coombes *et al*., 2017). Also other species growing on concrete, like oysters and corals, potentially contribute to the structures stability and longevity via bioprotection (Ido & Shimrit, 2015; Coombes *et al.*, 2017). Bioprotection can reduce the magnitude and frequency of structural maintenance, which translates into improved ecological stability (reduced anthropogenic intervention), as well as reduced maintenance costs.

The cleaning of concrete is often undertaken on health and safety grounds, especially in a marine environment when controlling algal biofouling on stepped surfaces. Continual water jet cleaning practices lead to a higher surface roughness, thereby increasing the surface area offering a bioreceptive surface for further, quicker and denser colonisation; these phenomena provoke and encourage each other (Hughes, 2013).

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[5] The penetration of chloride ion (which comes from salt containing chlorine) through pores into permeable concrete is called Chloride (or ion) ingress. Marine environments are one of the most significant and common sources of chlorides. Chlorides have little effect on hardened concrete but they increase the risk of (steel) reinforcement corrosion.

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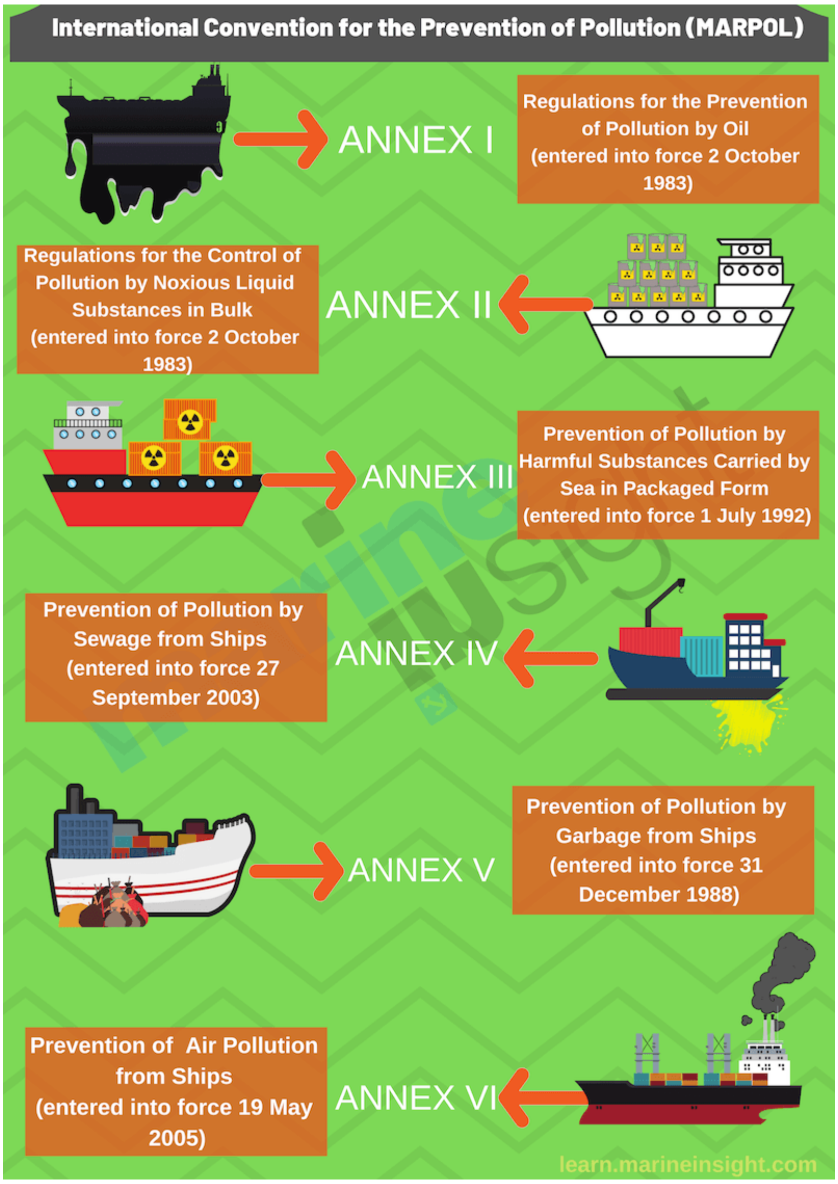
Annex 1: SOLAS and MARPOL

SOLAS Chapters (https://www.marineinsight.com).



MARPOL Annexes (https://www.marineinsight.com).

Annex 2: Factors for the Risk Assessment

From BG RCI 2017. General Topics Risk Assessment – Hazard Catalogue A 017e, Edition: October 2017.

Basic Organisational Factors

In this section you can check off organisational regulations, which you already apply in the company.

1 Basic Organisational Factors

- ☐ 1.1 Workplace-Related Training
- ☐ 1.2 Workplace-Related Operating Instructions
- ☐ 1.3 Coordination of Work
- ☐ 1.4 Hazardous Work
- ☐ 1.5 Use of Personal Protective Equipment
- ☐ 1.6 First-Aid Systems
- ☐ 1.7 Alarm and Rescue Measures
- ☐ 1.8 Hygiene
- ☐ 1.9 Organisation of Occupational Safety and Health
- ☐ 1.10 General Communication
- ☐ 1.11 Mandatory Testing of Work Equipment
- ☐ 1.12 Employment Restrictions

Risk and Stress Factors

In this overview you can select risk and stress factors, which are true for the company.

2 Hazards related to Workplace Design

- ☐ 2.1 Working Spaces
- ☐ 2.2 Traffic Routes
- ☐ 2.3 Falling on Even Ground, Slipping, Stumbling, Twisting one's Ankle, Missteps
- ☐ 2.4 Falling from a Height
- ☐ 2.5 Containers and Confined Spaces
- ☐ 2.6 Working close to Water

3 Hazards related to Ergonomic Factors

- ☐ 3.1 Heavy Physical Work
- ☐ 3.2 Physical Work Straining on one Side
- ☐ 3.3 Lighting
- ☐ 3.4 Climatic Conditions
- ☐ 3.5 Information Intake
- ☐ 3.6 Extent of Perception
- ☐ 3.7 Impeded Handling of Work Equipment
- ☐ 3.8 Standing Workplaces
- ☐ 3.9 Workstations

4 Mechanical Hazards

- ☐ 4.1 Unprotected Moving Parts of Machinery
- ☐ 4.2 Parts with Hazardous Surfaces
- ☐ 4.3 Means of Transport
- ☐ 4.4 Parts Moving Uncontrolled

5 Electrical Hazards

- ☐ 5.1 Principles
- ☐ 5.2 Hazardous Body Currents
- ☐ 5.3 Electric Arcs

6 **Hazards related to Substances**

- ☐ 6.1 Harmful Effects of Gases, Vapours, Aerosols, Dusts, Liquid and Solid Substances
- ☐ 6.2 Skin Exposure
- ☐ 6.3 Miscellaneous Impacts (Odours/Oxygen Deficiency)

7 **Hazards related to Fire and Explosion**

- ☐ 7.1 Fire Hazards related to Solids, Liquids and Gases
- ☐ 7.2 Hazards due to Explosive Mixtures
- ☐ 7.3 Thermal Explosions (Runaway Reactions)
- ☐ 7.4 Physical Explosions and Boiling Delays
- ☐ 7.5 Explosive Substances (Explosives)
- ☐ 7.6 Miscellaneous Explosive Material (e. g. Peroxides)

8 **Biological Hazards**

- ☐ 8.1 Targeted Activities
- ☐ 8.2 Non-Targeted Activities

9 **Hazards related to Special Physical Impacts**

- ☐ 9.1 Noise
- ☐ 9.2 Ultrasound
- ☐ 9.3 Whole-Body Vibrations
- ☐ 9.4 Hand-Transmitted Vibrations
- ☐ 9.5 Non-Ionising (Optical) Radiation
- ☐ 9.6 Ionising Radiation
- ☐ 9.7 Electromagnetic Fields
- ☐ 9.8 Hot or Cold Media – Cold or Hot Workplaces
- ☐ 9.9 Electrostatic Hazards
- ☐ 9.10 Overpressure/Partial Vacuum

10 **Mental Stress Factors**

- ☐ 10.1 Work Content/Work Task
- ☐ 10.2 Work Organisation
- ☐ 10.3 Social Relations
- ☐ 10.4 Working Environment
- ☐ 10.5 New Modes of Work

11 **Miscellaneous Risk and Stress Factors**

- ☐ 11.1 Field Work
- ☐ 11.2 Humans
- ☐ 11.3 Animals
- ☐ 11.4 Plants

Annex 3: Risk Register

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Cages	Aquaculture system	Cages		2.1	Diving operations		Due to extreme wind and wave conditions divers may get entangled in nets of net-cages during maintenance operations	People	Human life, accidents
Island	Modules	Deck of modules		2.3	Biofilm and/or liquids	Slippery surface	Due to biofilm and/or liquids in combination with platform motions the deck becomes slippery.	Ecosystem	Personal injury, accident, human life
Island	Modules	Deck of modules		2.3	Material fatigue (corrosion, material stress etc)	Uneven surfaces	Due to material fatigue the deck may become uneven	Infrastructure	Personal injury, accident, economic consequence, human life
Platform in general	Modules	Deck of modules		2.3	Biofilm and/or liquids	Slippery surface	Due to biofilm and/or liquids in combination with platform motions the deck becomes slippery.	People, Ecosystem	People falling: Personal injury, accident, human life. Cargo and unlocked goods slip: Economic consequence, Pollution/Societal Loss
Container Terminal	Crane, all types	All components requiring lubrication		2.3	Mishandling of lubricant use	Slippery surface / green water	Mishandling of lubricants during maintenance can result in creation of slippery surfaces and greatly contribute to workplace/environmental pollution if they find their way into water	People, Ecosystem	May cause: Pollution/societal loss, personal injury

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Module		Helideck		2.3	Slipping due to wet / iced deck	Slipping on helideck	Due to wet, iced conditions and motions people may slip on the helicopter deck	People	Personal injury
Island	Modules			2.4	Platform (relative) motions, wind conditions	People falling from platform	Due to motions and extreme wind conditions people may fall from platform	Ecosystem	Personal injury, accident, economic consequence, human life
Island	Modules			2.6	Failure of storm barrier	Green water	Due to high wave activity water comes onto the platform.	Ecosystem	Personal injury, accident, pollution/societal loss, economic consequence, human life
Island	Modules	Sub-Structure		2.6	Strong wave conditions	Vessels colliding with platform	Vessels colliding with platform due to strong wave conditions	Ecosystem	Personal injury, accident, economic consequence, human life
Island	Modules			2.6	Platform (relative) motions, wind conditions	People being trapped below or between platforms	Due to motions and extreme wind conditions people may become trapped below or between platforms.	Ecosystem	Personal injury, accident, economic consequence, human life
Island	Modules			2.6	Strong wave conditions	Ice drift colliding with platform	Ice drift colliding with platform due to strong wave conditions	Ecosystem	Personal injury, accident, economic consequence, human life
Container Terminal	Modules	Deck of modules	-	2.6	Extreme sea states, steep waves	Green water	Due to high waves water reaches the platform deck and steel containers on a steel deck with out any lock will slip easily if the module is inclined.	People, Equipment	Personal injury, accident, pollution/societal loss, economic consequence, human life

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Container Terminal	Crane, all types	Lifting gear	all	4.3	Badly rigged or locked load on the hook or in the spreader.	Loss of load	Not sufficiently locked loads may fall due to uncontrolled motions	Equipment, People, Ecosystem	In case people are in vicinity to the lift: personal injury, human life. Load hitting the deck or container hatch on board cause damage to the structure: Economic consequence, pollution/Societal Loss in case hazardous containers are lifted.
Island	Mooring	Mooring line		4.4	Mooring failure	Drifting of the platform	Due to the mooring failure the platform is drifting in an uncontrolled fashion	Infrastructure	Structural damage and collision, personal injuries, accidents, human life, economic consequence
Island	Modules	Connection between modules		4.4	Failure of connection system	Module separation	Due to failure of the connection system modules separate or collide.	Infrastructure	Structural damage and collision, personal injuries, accidents, human life, economic consequence
Island	Modules			4.4	Excessive weight (platform overloading, snow loads, marine growth flooding etc)	Sinking	Due to excessive weight a module may start (partially) sinking. Partial sinking can also result in tilting of the module.	Infrastructure	Personal injury, accident, pollution/societal loss, economic consequence, human life
Island	Modules	Unfixed items		4.4	Platform motions	Shifting/moving of unsecured items	Shifting and falling of items due to the movements of modules	Equipment	Personal injury, accident, economic consequence, human life

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Island	Modules			4.4	Multiple mechanical systems oscillating in cohesion with wave vibrations	Mechanical Resonance	Due to multiple mechanical systems vibrating in cohesion with wave vibrations mechanical resonance can occur	Equipment	Personal injury, accident, economic consequence, human life
Island	Modules, aquaculture system	Equipment	Cranes and capstans, net cages	4.4	Lifting operations using cranes and capstans, and net cages	Entanglement or crush	Due to motions and extreme wind and wave conditions loads might swing uncontrollably and net cages may move unexpected	Equipment	Personal injury, accidents
Island	Modules	Equipment	Sharp tools	4.4	Working with sharp tools	Prick, cut, puncture	Due to motions people may getting injured by sharp objects (knives, needles)	People	Personal injury, accidents
Platform in general	Modules	Connection between modules	all	4.4	Failure of connection system	Module separation	Due to failure of the connection system modules separate.	Infrastructure, Equipment	Collision between modules and other floating structures may occur and cause: economic consequence, Pollution/Societal Loss, Personal injury
Platform in general	Mooring	Mooring line	e.g. anchor, fairlead, winch, joint	4.4	Mooring failure	Drifting of the platform	Due to the mooring failure the platform is drifting off	Infrastructure, Equipment	Collision between modules and other floating structures may occur and cause: economic consequence, Pollution/Societal Loss, Personal injury

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Container Terminal	Crane, all types	Winding drum	all	4.4	Mechanical fault	Uncontrolled lifting	The drums break has a mechanical failure or the line slips, thus that the load is not lost, but lowers uncontrolled.	Equipment, People	Cargo may hit crane or other surrounding structures: Economic consequences, Pollution/Societal Loss. Hitting people causes: personal injury, or affects human life
Container Terminal	Crane, all types	All moving parts during a lift	all	4.4	Platform (relative) motions, wind conditions	Uncontrolled motions	Due to motions and extreme wind conditions loads might swing uncontrolled.	Equipment	Cargo may hit crane or other surrounding structures: Economic consequences, Pollution/Societal Loss. Hitting people causes: personal injury, or affects human life
Container Terminal	Crane, all types	All components requiring spare part change		4.4	Platform motions, wind conditions, sea states	Uncontrolled equipment parts	During repair/change of moving parts, sea states and wind may cause uncontrolled motion	Equipment, People, Infrastructure	Personal injury, Accident, economic loss
Container Terminal	Modules	Vacuum mooring system	Vacuum control / Power supply	4.4	Power loss or exceedance of maximum mooring force due to wind, current and or waves	Uncontrolled drifting of ULCV (Ultra Large Container Vessel)	Due to exceedance of limits or a power loss the vacuum mooring systems may fail. This causes the ULCV to possible drift of due to wind and current.	Equipment, infrastructure, people	The vessel may drift off causing a collision with other vessels or modules. This may cause significant damage to equipment infrastructure and people.

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Island		Wave energy converter	Connection	4.4	Failure of connection system by high wave loads	Damage to or failure of the structure of the energy converter(s)	High wave loads result in damage to the structural connections of the energy converter(s), which may result in capsizing and sinking of module(s)	Infrastructure	Personal injury, accident, economic consequence, human life
Island		Wave energy converter	Electrical component	4.4	Marine vessels or (larger) animals	Cable disconnection	Damage caused by (sea-going) vessels and animals may disconnect or damage grid connection cable(s)	Equipment, ecosystem	Personal injury, pollution, human life
		All		4.4	Motions having impact on lifting	Carry and lift	Motions affect carrying and lifting operations by persons and equipment leading to injuries of persons or damage to equipment	People, Equipment	Personal injury, accident
Island	Module			4.4	Collisions or corrosion	Crack of floater	Offshore operations may result in collisions with vessels or induce corrosion that may cause leakage of the floating modules, resulting in (partly) sinking	Infrastructure, equipment, people, ecosystem	Personal injury, health problem, accident, pollution, economic consequences, human life
Island	Modules			5.2	Storm conditions	Lightning Strikes	Due to storm conditions lightning strikes may occur on the platform	Ecosystem	Personal injury, accident, economic consequence, human life

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Modules, cages	Aquaculture system	Plastic fodder tubes used in sea-based production		5.2	Caused by static electricity from plastic fodder tubes used in sea-based production. Electricity is released when, for example, the tubes are sawn through or flushed with hoses	Voltage, electrocution	Due to unexpected water hoses while working with feed tubes workers may get exposed to voltage	People	Personal injury, accidents
Island	Module	Wave energy converter	Electrical compone nt	5.2	Environmental conditions or human faults	Cable break	Environmental conditions or human faults may cause damage to power cable	Equipment, people	Personal injury , accident, economic consequences
Island	Module	Wave energy converter	Electrical compone nt	5.3	Generator heavily stressed by storm wave conditions	Overheating of electrical component	Under storm wave conditions the generator is so heavily stressed that the electrical components are subjected to high thermal loads which may lead to fire	Equipment, infrastructure, people	Personal injury , accident, economic consequences
Island	Module	Wave energy converter	Mechanic al Power transmiss ion	6.1	Unexpected loadings induced by motions	Mechanical ruptures or failures of power transmission system	Due to unexpected loadings induced by motions (or otherwise) the power transmission system may fail, which may result in release of hydraulic fluid to the environment	Equipment, Ecosystem	Accident, pollution

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Island	Modules			6.1	Spills	Chemical hazards: Environmental contaminants from deck run-off	Spills may occur that may form a chemical hazard to food safety by the accumulation of toxins in seafood products. Also consider tainting (see OSPAR list of substances known to cause tainting)	People	Food safety
Island	Modules			6.1	Antifouling	Chemical hazards: Environmental contaminants from antifouling	Antifoulants can leach into the environment leading to a chemical hazard to food safety: the accumulation of toxins in seafood are hazards to the safety of aquaculture products.	People	Food safety
Island	Modules			6.1	Human sewage	Biological hazards: Infectious bacteria from human sewage	Bacterial pathogens, such as Enterococci and E. coli from human sewage and animal feaces may enter the environment from e.g. wastewater, run-off from deck, sewage and boat discharge.	People	Food safety
Island	Modules			6.1	Material lost from system	Physical hazards: Material lost from system	Small materials (e.g. glass, metal) that could be lost from the islands may end up in aquaculture products and be swallowed by humans (via food) or animals (via feed) should be considered.	People	Food safety
Island	Modules			7.1	Human error/ Electrical/ mechanical failure	Fire	Fire due to human error or electrical or mechanical failure	Equipment	Personal injury, health problem, accident, pollution/ societal loss, economic consequence, human life

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Island	Modules	Equipment		9.1	Machinery and Equipment	Noise pollution	Noise pollution caused by machinery and equipment	Equipment	Pollution/ Societal loss/ Health problem
Island	Modules	Equipment		9.1	Machinery and Equipment	Noise pollution	Noise pollution caused by machinery and equipment	Equipment	Pollution/ Societal loss/ Health problem
Island	Modules			9.3	Platform motions	Vibration	Due to platform motions the platform will vibrate	Ecosystem	Health problem, economic consequence
Island	Modules			9.3	Platform motions	Vibration	Installations on the island cause vibrations	Ecosystem	Health problem, economic consequence
Crane system				10.4	Platform (relative) motions, wind conditions	Uncontrolled lifting motions	Due to motions and extreme wind conditions loads might swing uncontrollably.	Equipment	Personal injury, accident, pollution/societal loss, economic consequence, human life
Container Terminal	Modules	Cranes	all	10.4	Waves or wind cause motion of module and crane	Uncontrolled motion	Motion of module, might affect the crane drivers ability to control the crane	People	people working at exposed locations on a moving structure may experience high acceleration, that can affect their ability to work and their personal health: personal injury, health problem
Island	Module	O&M Hub		11.2	Diseases, accident, injuries	Malfunctioning of staff	The staff suffers diseases and accidents during their stay that cause downtimes	People, equipment	Heatlth problem, economic consequences

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Island	Modules	Sub-Structure		11.4	Lack of natural-light reaching water	Algae blooms	Algae blooms due to lack of natural light reaching water	Ecosystem	Pollution/societal loss, economic consequence, Health problem.
Platform in general	Modules	Cranes and other large structures		1.11, 1.9	Fatigue in cranes and other large structures	Permanent crane or large structure failure	Due to cyclic loading of waves and wind and due to high accelerations at crane top levels, cranes on the space@sea modules are much more prone to fatigue damage than cranes onshore. A consequence might be cracks or other signs of fatigue causing the crane to have to be put out of operation prior to its designed lifetime.	Equipment, infrastructure	Replacement of a crane module prior to the designed lifetime causes large costs. Potentially without fatigue detection, structure failure may cause more immediate damage to modules and people.
Platform in general	Modules	Structures installed on modules on space@sea location		11.1, 10.2, 4.4	Incorrect transportation and installation analysis of structures	Equipment damage, uncontrolled motions	The hydrodynamic response of the platform and sea state in the berth behind floating breakwaters is very complex to model. Incorrect assumptions may cause installations to happen at environmental conditions that may cause uncontrollable motions and damage during installation of large structures and or smaller substructures.	Equipment, people	Damage to equipment and in worst case also to people working around the installations.
Vessel				2.2 / 4.3	Transport	Loss of transport vessels	Due to extreme wind and wave conditions vessels (workboats) may sink	People, equipment	Human life, accidents, equipment, economic consequence

System	Subsystem	Component	Sub-Component	BG RCI A017	Cause of Hazard	Name of Hazard	Detailed Description of Hazard	Type of hazard	Risk Dimension/Consequence
Island	Modules	Equipment	Several (module, vessel, cage, ladder)	2.3 / 2.4	Platform (relative) motions, wind conditions	Falls of people	Due to motions and extreme wind conditions people loose grip from equipment (e.g. ladders, boats, cages, feeder barges)	People	Personal injury, accident, human life
Island	Modules	Equipment	Several (module, vessel, cage, ladder)	2.3 / 2.4	Platform (relative) motions, wind conditions	Hit by objects	Due to motions unfixed items (tools, wires, ropes, trapdoors, etc) may shift or fall	Equipment	Personal injury, accidents
Modules, vessels, cages				2.4 / 2.6	Unexpected motions or sudden wind during transfer of people	Man overboard	Due to extreme wind and wave conditions man may fall overboard from extreme and unexpected movements of vessels (workboats) and modules	People	Human life, personal injury, accident
Container Terminal	Modules	Cranes	Motion compens ation system	4.4, 1.11	Failure of the motion compensation systems in the gantry cranes	Uncontrolled cargo motions	Failure in the motion compensation systems and load control systems, i.e. due to power loss, multiple sensor failure, control system instability or other unexpected failures. May cause uncontrolled load motions	Equipment	The cargo may hit the crane, vessel, or other equipment causing significant damage.