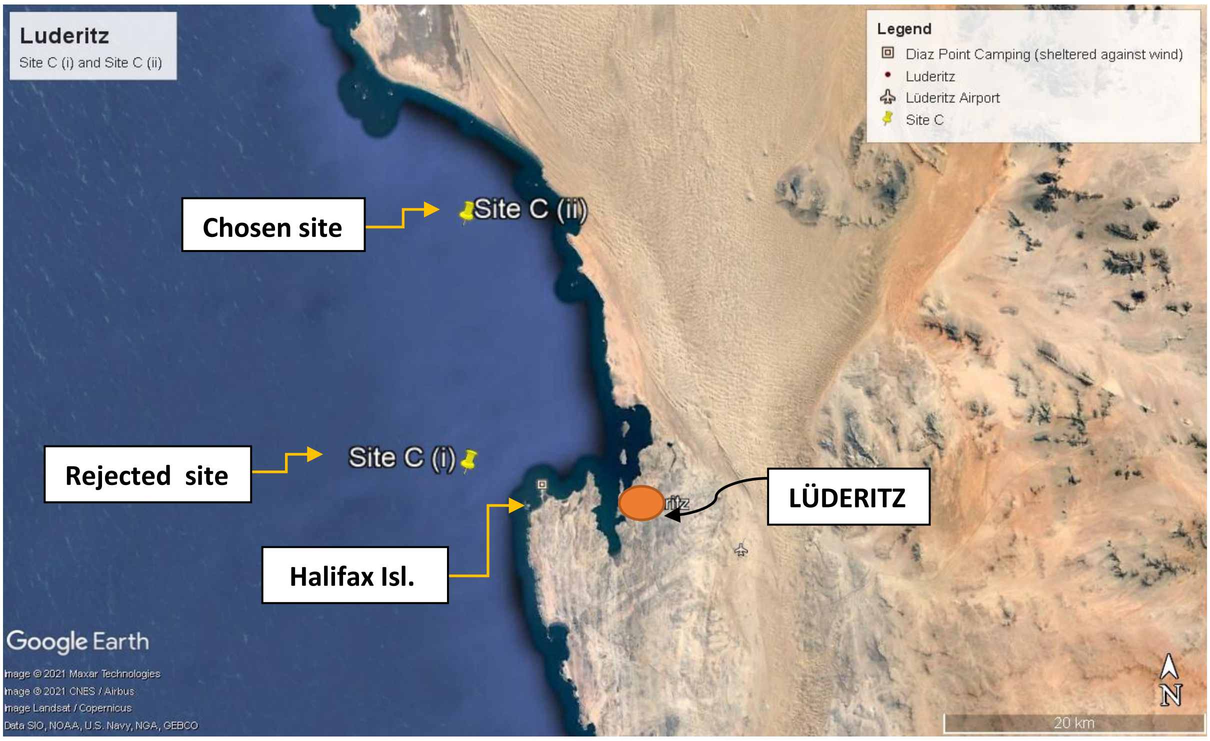
ENVIRONMENTAL MANAGEMENT PLAN (EMP)

for

LILONGENI FISH-FARMING (Pty) Ltd.

on

FINFISH CAGE CULTURE OFFSHORE, LÜDERITZ, //KARAS REGION, NAMIBIA



Proposed site for finfish cage culture at site C (ii) north-west of Lüderitz at 26º27'00'' Latitude south and 15º00'00'' Longitude east (26.45 and 15.00).

Note: Site C (i) was the site proposed by the Proponent as per the Feasibility study (InnovaSea, 2020).

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1. INTRODCUTION TO THE EMP

An **EMP** is an environmental management tool used to ensure that undue or reasonably avoidable adverse impacts of the construction and operation, and decommissioning of a project are prevented and that the positive benefits of the projects are enhanced.

This EMP report lays out the parameters for the environmental management of the project through construction, operation and if necessary decommissioning. The EMP equips those responsible (Proponent and contractors) for the environmental management with templates listing what needs to be monitored, to ensure that the goal of protecting the environment and mitigating impacts is being achieved.

This EMP, need to be read in conjunction with the EIA report, which outlines all the environmental aspects that must be monitored throughout the construction and operation of the proposed finfish cage culture. It is to be noted that an EMP is a living document and if environmental conditions change or project parameters change significantly then the EMP and monitoring must be adapted accordingly.

The ultimate goal of any proposed development is to ensure that the environment and socio-economic status of the area are well protected through good governance and monitoring procedures that are able to detect and quickly rectify any adverse impact on the environment or community caused by the project.

2. ENVIRONMENTAL REGULATORY FRAMEWORK

The main source of legislation is the Constitution of the Republic of Namibia (1990) which makes provision for the creation and enforcement of environmental policies. According to Article 95 (Chapter 11) of the constitution, the state shall actively promote and maintain the welfare of the people by adopting inter alia, policies aimed at maintaining the ecosystems, essential ecological processes and biological diversity of Namibia and utilization of living natural resources on a sustainable basis for the benefit of all Namibians, both present and future.

The Ministry of Fisheries and Marine Resources (MFMR) is the competent authority for aquaculture or mariculture activities in Namibia. The Aquaculture Act (No. 18 of 2002) is the most important regulatory framework that provides regulations and control of aquaculture activities in Namibia, for the sustainable development of aquaculture resources. Several explicit references to the environment and its protection are contained in the Aquaculture Act, which provides for environmental impact assessments, and impact mitigation, disease and pollution control and prevention.

On the other hand, the Ministry of Environment, Forestry and Tourism as per the Environmental Management Act, the Department of Environmental Affairs and Forestry (DEAF) implements environmental laws and guides the environmental impact assessment process. The three (3) main Acts and Regulations that impact on this project include:

- Environmental Management Act 7 of 2007
- Environmental Impact Assessment Regulations (EIA) of 2012
- Aquaculture Act No. 18 of 2002

The environmental regulatory framework is discussed in more detail in Chapter 4 of the EIA report.

3. TOR FOR THE EMP

Lilongeni Fish-Farming (Pty) Ltd. appointed Atlantic Consulting Services cc to conduct an EIA for the finfish cage culture offshore from Lüderitz. Atlantic Consulting Services cc conducted an environmental scoping exercise and lodged an application for an Environmental Clearance Certificate (ECC) with the Ministry of Environment, Forestry and Tourism (MEFT). The application was verified and MET requested for an EMP. As per instruction of the EC office of MEFT, this EMP should be read together with the accompanying EIA report. This EMP report took due consideration of:

- ➢ The necessity for an EMP report
- ➢ Detailed project description
- ➢ Review of relevant policies and legislation
- ➢ The development of a legislative framework compliance plan
- ➢ Identification of the possible and known impacts of the project
- ➢ Development of an Environmental Management Plan (EMP) with workable mitigation measures for adoption

4. PROJECT DESCRIPTION

- The Proponent Lilongeni Fish-Farming (Py) Ltd. intends constructing a mariculture farm offshore in the Atlantic Ocean north-west of Lüderitz to farm with two (2) indigenous fin-fish species and one (1) foreign fin-fish species **(Fig. 1).** A project of this magnitude, with a financial investment of 65 million U$ dollar, will contribute in stimulating growth and confidence in the coastal town of Lüderitz. In addition:
    - o The socio-economic importance of this Mariculture project can hold for Namibia in the light of job creation and related industries

- Recognizing the call made by HE President Geingob in the HPPII and NDP5 which both refer to the Blue Economy, a natural resource which needs to be optimized
- The development of the Mariculture sector in the vast expanse of the Atlantic Ocean of Namibia can contribute to the socio-economic upliftment of Namibia's coastal towns
- The Blue Economy Agenda and NDP5 can further contribute and assure that certain aims and objectives of VISION 2030 can be achieved
- Mariculture in Namibia can be the pathway to unlock the potential that the Namibian coastline can provide for a sustainable ocean economy

The Vision and Mission of the Company is as follows:
***Vision**:* To become a major Namibian sea fish ranching company serving the economy of Namibia by developing the first mariculture cage farm in the Atlantic Ocean of Namibia.
***Mission**:* To develop Lüderitz into an international fish farming hub to compensate for the shrinking global capture fishery and to keep the existing underutilized fish industries in Lüderitz utilized.

Based on the Feasibility Study conducted by the Proponent the following four (4) species to be farmed with include:

- ***Argyrosomus inodorus*** **(Silver cob) - offshore**
- ***Seriola lalandi*** **(Yellowtail kingklip) - offshore**
- ***Salmo salar*** **(Atlantic salmon)- offshore**
- ***Argyrosomus coronus*** **(Dusky cob) – onshore** (future expansion)

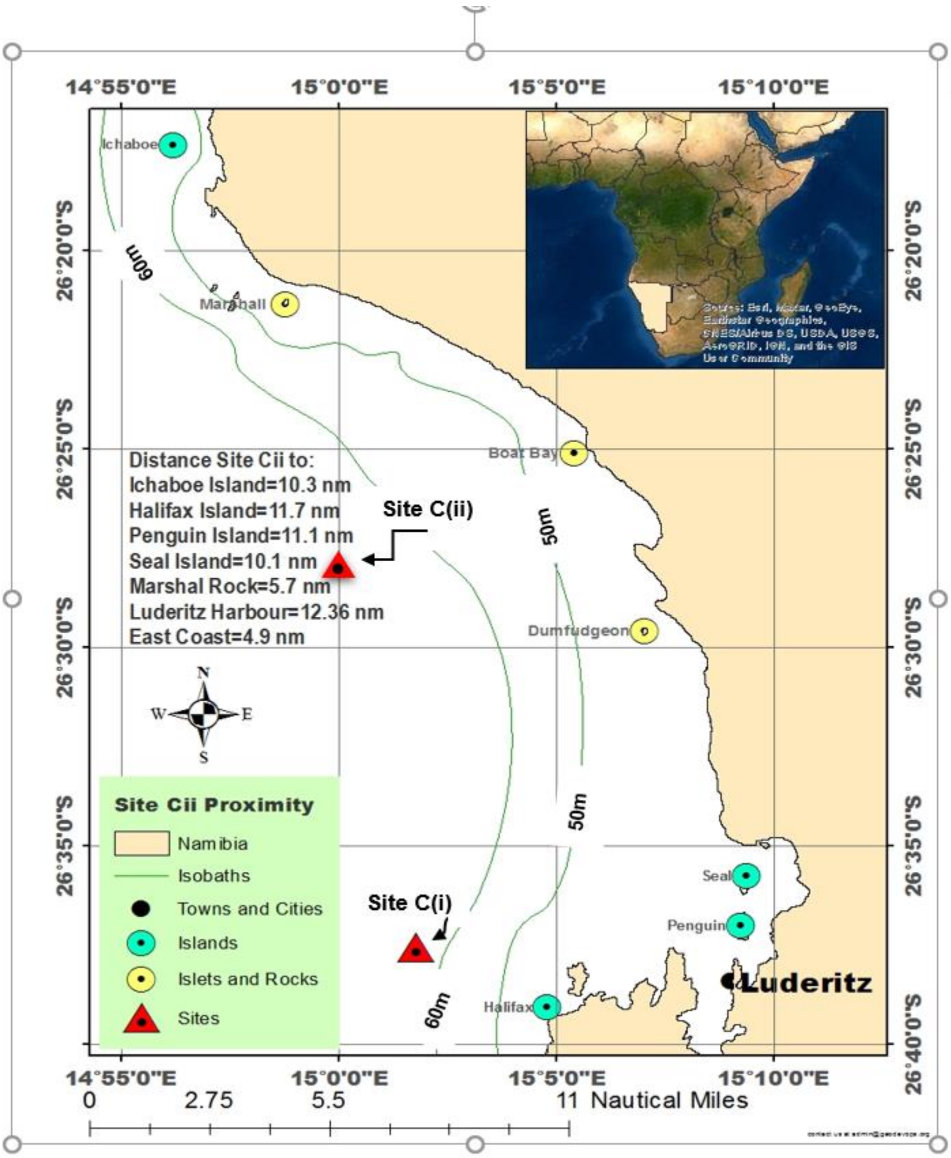


Figure 1: Proposed site for finfish cage culture at site C (ii) north-west of Lüderitz at 26º27'00'' Latitude south and 15º00'00'' Longitude east (26.45 lat. and 15.00 long.)

Note: Site C (i) was the original site proposed by the Proponent which is in proximity of Halifax island and the jackass penguin foraging grounds.

Onshore and Offshore operation:

- *Fish processing factory* – Lüderitz currently has fish processing facilities which are underutilized due to the decline of the fishing sector over the past decades; in addition there are also warehouses standing empty which could be re-designed to house a hatchery and quarantine facility

- *Annual Production (at sea)* of 36 000 metric tonnes mainly for the export market to Europe (Germany) Asia (Japan) and the USA – to be processed onshore
- *Quarantine facility and a hatchery for future expansion for brood stock and fingerling production*

Initially fingerlings (cob) will be sourced from SANUMARC - UNAM (Henties Bay). However, through the MFMR, permission will be requested to catch brood stock. The brood stock will be kept onshore Lüderitz where a hatchery will be established to sustain the annual production of ca 12 000 tonnes for the silver cob

- *Employment*
  - The magnitude of this project will be of direct benefit to the people in the coastal town of Lüderitz.
  - <u>*Onshore:*</u> Administration (5x); Stores manager – equipment (1x) and labourers (4x); Quarantine facility (6x); Hatchery (8x); Fish processing (25x); plumber and electrician (2x); Feedstore manager (1x) and labourers (6x); Lab technicians (2x), workhand (2x) *TOTAL: 62*
  - <u>*Offshore:*</u> Service Vessel: Captain (1x), 2nd Officer (1x), 1st and 2nd Engineer (2x), IT specialist – monitoring (2x), deckhands (4x), Lab technicians (2x), workhand (2x) *TOTAL: 14*
  - Total persons to be initially employed: 76 staff and to be increased as production increases to a maximum of 36 000 metric tonnes annually (Phase 1 and 2).

This operation will provide needy opportunities for highly skilled people in a wide range of expertise from the Lüderitz community.

Offshore - The cage cluster system of submersible cages will be deployed (design by BW FishFarm, 2021). The outlay and holding capacity will be as follows:

<u>Cage cluster:</u>

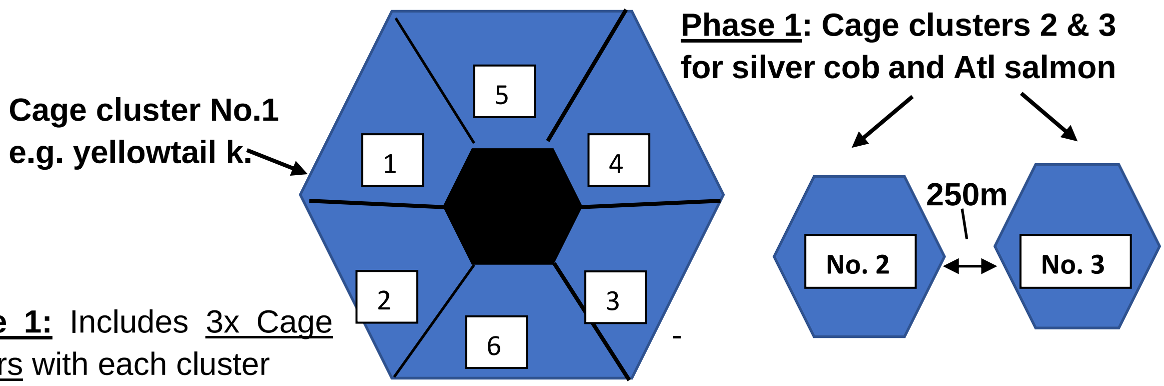
Six 'cluster cages' to be deployed in Phases in a 'cluster' **(Fig. 2)** for each species and separated by 200m from each other. Each cage cluster having the following capacity and output potential:

- Each sub-unit in a cage cluster has a water volume of 85 000m^3
- 1 x cage cluster (each with 6 sub-cages): total water volume of 500 000m^3
- Stocking density of 16 fish/m^3 (ca. 1.5kg/fish) i.e. 24kg/m^3.

- Total output for each cage sub-unit = ca. 1 900 tonnes
- Total output per cage cluster = ca. 12 000 tonnes

<u>Deployment of cage clusters:</u>

- <u>Phase 1</u>: 1x cage cluster (comprising of four sub-units: 1 to 4), with a cage cluster having a holding capacity of ca. 7 500 tonnes for silver cob **(Fig.2)**.
- <u>Phase 1</u>: 2x cage clusters (each comprising of four sub-units: 1 to 4), with each cage cluster having a holding capacity of ca. 7 500 tonnes for yellowtail kingklip and Atlantic salmon respectively **(Fig.2)**.
- <u>Phase 2:</u> To add cages 5 and 6 to each cage cluster for yellowtail kingfish and Atlantic Salmon – each cage cluster with a holding capacity of ca. 12 000 tonnes for each species respectively
- <u>Phase 3:</u> Future expansion: 2x cage clusters (each comprising of six sub-units: 1 to 6), with each cage cluster having a holding capacity of ca. 12 000 tonnes for yellowtail kingfish and Atlantic salmon respectively **(Fig.2)**.
- Initially a water surface area of 250ha is being required and with future expansions to be increased to a maximum of 500ha.



<u>Phase 1:</u> Includes <u>3x Cage clusters</u> with each cluster comprised of six separate management cage units

Figure 2: Schematic example of a "cage cluster" with a total water capacity of ca 500 000m^3 producing approximately 12 000 tonnes fish per 24 month cycle (pending on species) conservatively stocked at 16 fish/m^3 (ca 1 to 1.5kg/fish). Based on BW FishFarm - Nordic Matrix, 2020 and 2021.

Below **(Fig. 3),** is an example of a cage cluster deployed in the sea, which consists of six units. The cage clusters, via a hydraulic system, can be submersed during times of rough seas.

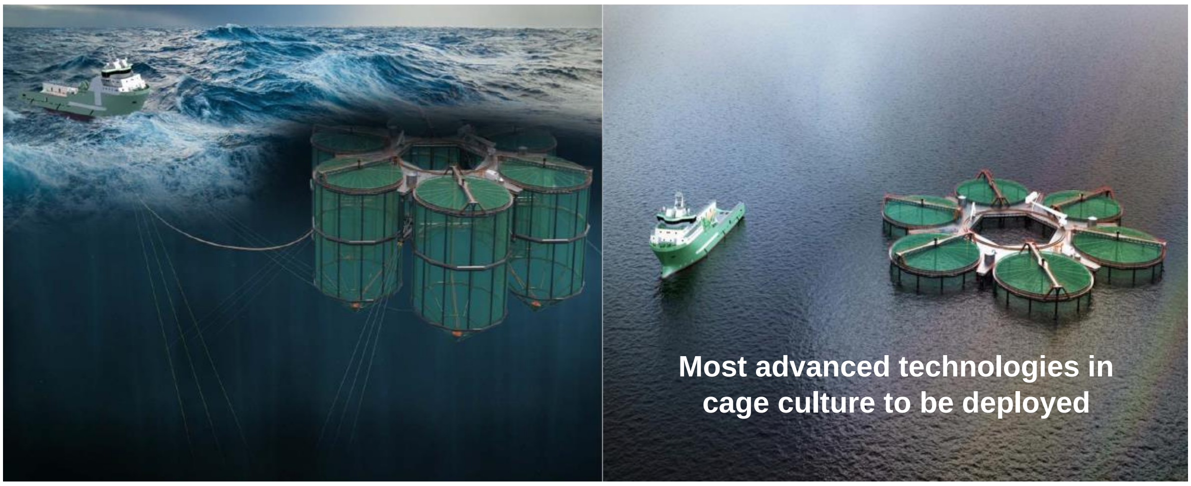


Figure 3: An example of a cage cluster, also referred to 'pens', to be deployed at the proposed site C (ii) (BW FishFarm, 2021).

The cages will be constructed onshore and taken to the site by the Service Vessel.

5. SITE SELECTION AND LIMITATIONS

A feasibility study on site and species selection was conducted by InnovaSea (2020). This study recommended four (4) alternative sites along the Namibian coast which included:

- **Site A – north of Walvis Bay** (22° 50' 8'' Latitude south and 14° 24' 13'' Longitude east)
- **Site B – south of Walvis Bay** (23° 00' 20'' Latitude south and 14° 20' 56'' Longitude east)
- **Site C – west of Lüderitz** (26°37'40'' Latitude south and 15°01'53'' Longitude east)
- **Site D – inshore true west of Oranjemund** (28°41'27'' Latitude south and 16°17'25'' Longitude east)

The site chosen for the proposed finfish cage culture will be ca. 12nm north-west of Halifax island**,** based on baseline studies, public meetings and one-on-one meetings, is positioned at 26º27'00'' Latitude south and 15º00'00'' Longitude east (26.45 lat. and 15.00 long.).

The unavailability of detailed specifications of the type of nets to be installed and the final design layout of the finfish cage culture to be deployed offshore, has placed limitations on the data available to the consultants for prediction of actual impacts. However, this EMP, on the proposed design, construction and operation of this finfish cage culture has created the opportunity to influence the technical design and as a result incorporate mitigation measures early in the project design stage.

6. IMPACT ASSESSMENT

The determination of whether an effect is significant per the EIA Regulations combines professional judgement with consideration of the following:

- The sensitivity of the resource or receptor under consideration.
- The magnitude of the potential effect occurs because of the Proposed Development.
- The type of effect, i.e., adverse, beneficial, neutral, or uncertain.
- The probability of the effect occurring, i.e., certain, likely, or unlikely; and
- Whether the effect is temporary, permanent and/or reversible.

A generalised methodology for assessing significant effects is detailed below, however, each technical area will have a specific assessment methodology which may vary from that detailed in the following subsections.

Sensitivity of the receptors

The sensitivity of the baseline conditions, including the importance of environmental features on or near to the Proposed Development or the sensitivity of potentially affected receptors, will be assessed in line with best practice guidance, legislation, statutory designations, professional judgement, and Marine Evidence-based Sensitivity Assessment. The Table 1 below details a general framework for determining the sensitivity of receptors.

Table 4: Method assessment for sensitivity of the receptors.

Sensitivity of receptors	Definition
Very High	The receptor has little or no ability to absorb change without fundamentally altering its present character, is of very high environmental value, or international importance
High	The receptor has a low ability to absorb change without fundamentally altering its present character, is of high environmental value, or national importance
Medium	The receptor has a moderate capacity to absorb change without significantly altering its present character, has some environmental value, or is of regional importance

Low	The receptor is tolerant of change without detriment to its character, is low environmental value, or local importance
Negligible	The receptor is resistant to change and is of little environmental value

Magnitude of effect

The magnitude of potential effects was identified through consideration of the Proposed Development, the degree of change to baseline conditions predicted because of the Proposed Development, the duration and reversibility of an effect and professional judgement, best practice guidance and legislation. General criteria for assessing the magnitude of an effect are presented in the Table 2 below.

Table 5: Method assessment for the magnitude of the effect.

Magnitude of effect	**Definition**
High	A fundamental change to the baseline condition of the asset, leading to total loss or major alteration of character
Medium	A material, partial loss or alteration of character
Low	A slight, detectable, alteration of the baseline condition of the asset.
Negligible	A barely distinguishable change from baseline conditions

Significance of the effect

The sensitivity of the asset and the magnitude of the predicted effects was used as a guide, in addition, to professional judgement, to predict the significance of the likely effects. The Table 3 below summarises guideline criteria for assessing the overall effect and whether this is significant.

Table 6: Method assessment for magnitude of the effect.

Magnitude of effect	**Sensitivity of receptor**				
	Very High	***High***	***Medium***	***Low***	***Negligible***
High	Major	Major	Moderate	Moderate	Minor
Medium	Major	Moderate	Moderate	Minor	Negligible
Low	Moderate	Moderate	Minor	Negligible	Negligible
Negligible	Minor	Minor	Negligible	Negligible	Negligible

The significance effects predicted for the proposed finfish farming that is categorised as **Major** or **Moderate** are considered as *'significant'* in this EIA and are shaded in red colour in the above table. Zero magnitudes of change upon a receptor will result in no effect, regardless of sensitivity.

Cumulative effects

Per the EIA Regulations, this report will also consider cumulative effects. These are the effects of incremental changes caused by past, present or reasonably foreseeable future actions in conjunction with the Proposed Development. Two types of effects will be considered in the cumulative assessment.

- The first is the combined effects of individual effects such as benthic effects and water column effects resulting from the proposed Finfish Farm Project.
- Secondly, are the combined effects of the proposed Finfish Farm Project with other several developments in the Lüderitz area that may be insignificant on an individual basis but have a significant effect when combined, such as effluents or landscape and visual effects.

Table 4 below provides a summary of the potential impacts that may occur during the construction and operational phase both offshore and onshore operations.

Table 4a: Offshore potential impacts and their significance during the construction and operational phase.

Activity / Field	Potential Impacts: Construction	Significance	Mitigation
Socio-economic	Job creation	High +ve	None
Fixing of Buoys to the substrate	Sediment (fauna and flora disturbance)	High -ve	Expert divers to be deployed to ensure that minimal disturbance to the sediments occurs
Contamination of the water column effect due to anchoring of buoys	Water quality	Medium -ve	Due to the Ekman offshore transport any sedimentation will be displaced westwards within a day
Increased daily shipping activity at site	Could possibly attract / distract birds and marine mammals	Low -ve	This is a remote isolated area
Noise pollution and increased activity	On the marine fauna	Low -ve	No more than 2 vessels will be

			operating at a time during the construction phase
Oil, diesel	Potential spillage	Medium -ve	All procedures to be in place to prevent such an event
Workforce – their safety	Rough seas	High -ve	During stormy weather safety of the workforce will be considered
Activity / Field	**Potential Impacts: Operation**	**Significance**	**Mitigation**
Farm with native fish species	Disease transmission to and from farmed fish	High -ve	The fish in the cages will be monitored daily. Any mortality or signs will be investigated on the Service Vessel by a Pathologist. Fingerling prior to be taken to the offshore cages are kept and monitored at the quarantine facility onshore.
Farm with foreign fish species	Disease transmission to and from fish	High -ve	The fish in the cages will be monitored daily. Any mortality or signs will be investigated on the Service Vessel by a Pathologist. Fingerling prior to be taken to the offshore cages are kept and monitored at the quarantine facility onshore.
Socio-economic: at the Harbour	Increased activity at the harbour	High+ve	The program schedules of Namport at Lüderitz to be adhered too.
Socio-economic: skilled labour force	Fatigue	High +ve	Work to be conducted in shifts and staff

on the Service Vessel			change to be on a monthly basis
Fish processing, dead fish and other organic material	Attraction of birds and other marine mammals	Medium +ve	No fish will be processed at sea. Dead fish will be discarded onshore. All organic kitchen food will be taken onshore
Contamination of the water column + sediments	Waste feed accumulation	Low -ve	Feeding is automated and will be monitored and stopped once fish discontinue feeding
Safety of the workforce	During repairs, harvesting and cleaning of cages	Low -ve	During rough sea conditions the workforce will be kept in safety of the Service Vessel. Only professional divers will be hired
Contamination of the water column + sediments	Faeces accumulation	Low -ve	Feeding is automated and will be monitored and discontinued manually once fish stopped feeding
Harvesting of fish	Attraction of birds	Low -ve	During harvesting no fish will be seen by potential predators as fish get sucked up by a pipe directly on board the Service Vessel.

Table 4b: Onshore potential impacts and their significance during the construction and operational phase.

Activity / Field	Potential Impacts: Construction	Significance	Mitigation
Socio-economic	Job creation	High +ve	None
Increased vehicle traffic	The surrounding road network at which the quarantine facility will be constructed	Medium -ve	Adequate road signs will be placed in consultation with Lüderitz Road Traffic department

Renovation of existing infrastructure (cement, brickwork, paint, plumbing electrical etc.)	Increased noise, personal activity on site and dust pollution	Medium -ve	Protocols in place by Lüderitz Town Council which are applicable for any development, will be followed and adhered to
Noise and dust pollution	On the workforce and local community	Low -ve	Measures in place: ear and nose protectors
Workforce – safety	Accidents e.g. fall off scaffolding	Low -ve	Safety of the workforce will be no. 1 at all times
Activity / Field	**Potential Impacts: Operation**	**Significance**	**Mitigation**
Recirculating (RAS) system	Offset of waste water to the environemnt	High -ve	Only treated and lab tested water will be pumped back into the ocean: protocols for this are already in place e.g. at the abalone mariculture farm and existing fish processing factories
Fish processing	Disposal of waste (organic) and water	Low -ve	Existing fish processing factory to be utilized with all its restrictions and protocols in place
Lüderitz harbour	Increased activity at the harbour	Medium +ve	The program schedules of Namport at Lüderitz to be adhered too.
Socio-economic: skilled labour force	Night shift fatigue	High +ve	Work to be conducted in shifts for night duty staff at quarantine facility
Feedstore management	Attraction of rats and possibility of feed becoming moist	Low -ve	Rat proof store and use of pesticide where necessary All feed to be placed on pellets
Safety of the workforce	Offloading and loading of feed	Low -ve	At all times all safety precautions to be strictly adhered to and

	Fish processing at factory Increased harbour activities		workforce to be supplied with: safety shoes, appropriate attire, gloves, hard hats whenever necessary
Waste	Disposal of general waste	Low -ve	Lüderitz Town Council laws to be followed and adhered to

7. ONSHORE AND OFFSHORE FACILITIES AND ACTIVITIES

7.1 Onshore facilities and activities

The facilities will include: an administration block, feed and equipment store, laboratory and a quarantine facility for the fry / smolt which are initially to be imported. A Recirculating Aquaculture Systems (RAS) will be constructed to accommodate the quarantine facility **(Fig. 4)**; future expansion will include a hatchery and grow-out ponds for the dusky cob, which requires water temperatures above 20ºC.

Fish processing and freezer facilities will be leased from existing fish factories currently running at low capacity due to the decline in the capture fishery.

The major activities onshore include:

- The day to day operation of the quarantine facility for the three fish species to be farmed with
- Fish processing (lease of existing facilities)

Future development will include a hatchery for yellow tail kingklip and both cob species and grow-out ponds for the dusky cob.

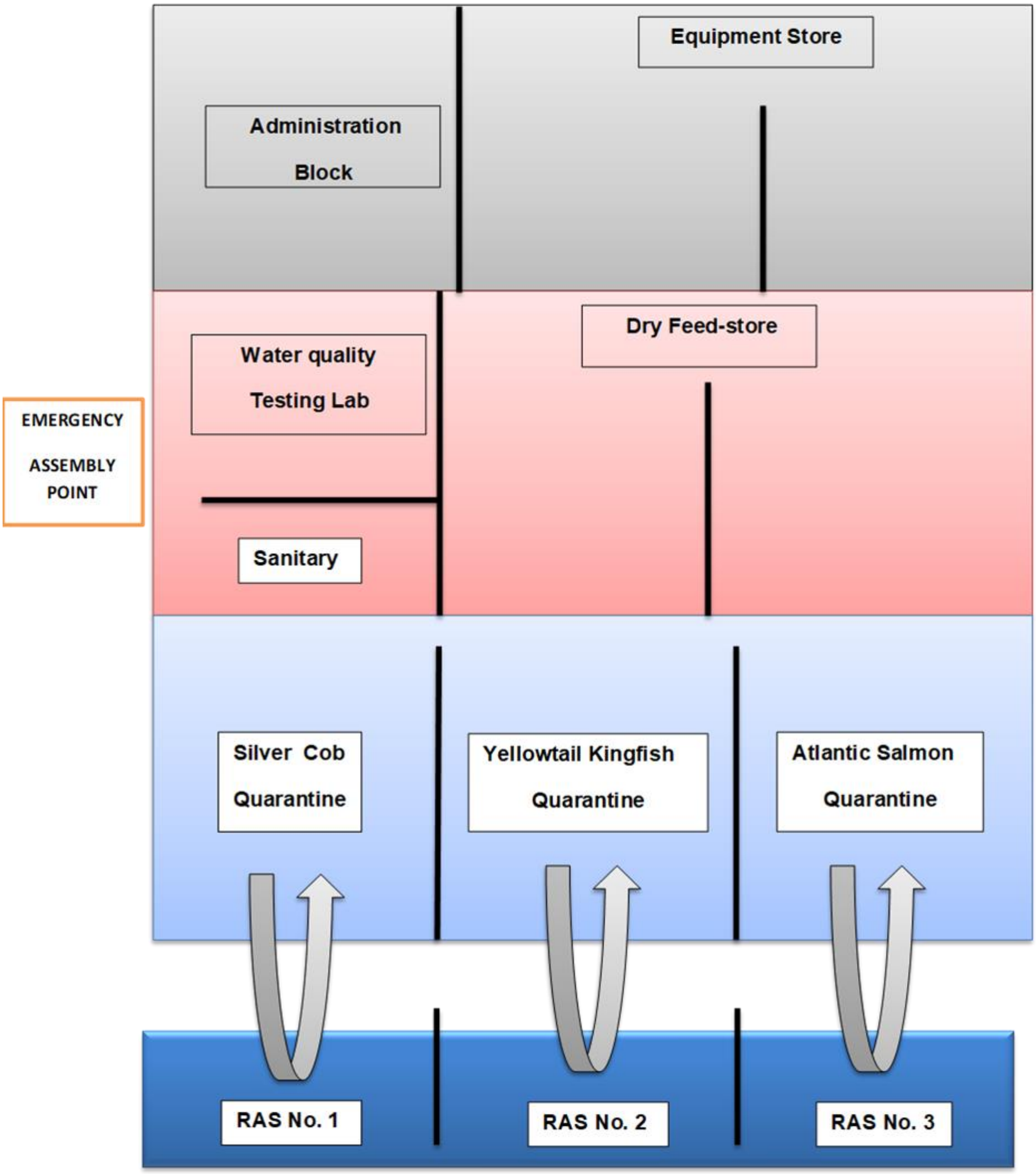


Figure 4: Schematic presentation of the onshore facilities for the Lilongeni Fish-Farming (Pty) Ltd.

The **Recirculating Aquaculture System** (RAS) technology has shown significant advances. To mitigate the serious water pollution caused by the rapid expansion of the aquaculture industry in recent years, the development of improved aquaculture systems with more efficient water usage and less environmental impact has become essential.

Advantages of RAS include high density production, controlled farming environments and the ability to establish systems close to markets.

What is a Recirculating Aquaculture System?

Recirculating aquaculture systems represent a new way to farm fish. Instead of the traditional method of growing fish outdoors, this system rears fish at high densities, in indoor tanks with a "controlled" environment (Halvorson & Smolowitz, 2009). Recirculating systems filter and clean the water for recycling through fish culture tanks. Water is typically recirculated when there is a specific need to minimize water replacement, to maintain water quality conditions which differ from the supply water, or to compensate for an insufficient water supply.

There are innumerable designs for recirculating systems and most will work effectively if they accomplish aeration, removal of particulate matter, biological filtration to remove waste ammonia and nitrite, and buffering of pH. These processes can be achieved by biofilters. These are living filters composed of a medium (corrugated plastic sheets, beads, or sand grains) upon which a film of bacteria grows. The bacteria provide the waste treatment by removing pollutants. The two primary water pollutants that need to be removed are (1) fish waste (toxic ammonia compounds) excreted into the water and (2) Uneaten fish feed particles. The biofilter is the site where beneficial bacteria remove (detoxify) fish excretory products, primarily ammonia.

Reoxygenating the culture water as it returns to the fish tank is crucial. Oxygen is the first limiting factor in recirculating aquaculture systems and with less than the required levels most fish and other aquatic organisms will die in a very short period of time. It is also critical that biofilters have access to adequate oxygen. Biofilters are homes to nitrifying bacteria, which are aerobic (use oxygen during respiration). Furthermore, nitrification, the conversion of ammonia to nontoxic nitrate by the bacteria, cannot occur without the presence of oxygen.

The advantages of farming in RAS are:

- Fully controlled environment for the fish
- Low water use
- Efficient energy use
- Efficient land use

- Optimal feeding strategy
- Easy grading and harvesting of fish
- Full disease control

Constraints of Recirculating Aquaculture Systems

To allow the use of RAS, there are a few constraints in respect of infrastructure, feed and staff:

- Necessity for electricity 24/7
- Good water source, preferably borehole
- Good fish feed quality, preferably high protein and fat extruded diets with high digestibility
- Technically skilled staff able to work in a medium tech environment

Recirculation Aquaculture Systems

Recirculation aquaculture is essentially a technology for farming fish or other aquatic organisms by reusing the water in the production. The technology is based on the use of mechanical and biological filters, and the method can in principle be used for any species grown in aquaculture such as fish, shrimps, clams, etc. Recirculation technology is however primarily used in fish farming, and this 'guide' is aimed at people working in this field of aquaculture.

Recirculation Aquaculture Systems **(Fig. 5)** are growing rapidly in many areas of the fish farming sector, and systems are deployed in production units that may vary from huge plants generating many tonnes of fish per year for consumption to small sophisticated systems used for restocking or to save endangered species. In this case the RAS will be initially used to accommodate smolt / fry / fingerlings imported, during the quarantine period which may range from 1 month to 3 months.

Recirculation can be carried out at different intensities depending on how much water is recirculated or re-used. Some farms are super intensive farming systems installed inside a closed insulated building using as little as 300 litres of new water, and sometimes even less, per kilo of fish produced per year. Other systems are traditional outdoor farms that have been rebuilt into recirculated systems using around 3 m^3 new water per kilo of fish produced per year. For example, a traditional flow through system for trout will typically use around 30 m^3 per kilo of fish produced per year.

Figure 5: Indoor Recirculating Aquaculture Systems (RAS).

Another way of calculating the degree of recirculation is using the formula:

$$\frac{(Internal\ recirculation\ flow)}{(internal\ recirculation\ flow + new\ water\ intake)} \times 100$$

From an environmental point of view, the limited amount of water used in recirculation is beneficial as water has become a limited resource in many regions, especially at the coastal town of Lüderitz. The limited use of water make it much easier and cheaper to remove the nutrients excreted from the fish as the volume of discharged water is much lower than that discharged from traditional fish farms.

Most interesting though, is the limited use of water gives a huge benefit to the production inside the fish farm. Traditional fish farming is totally dependent on external conditions such as the water temperature of the river, cleanliness of the water, oxygen levels, or weed and leaves drifting downstream and blocking the inlet screens, etc. In a recirculated system these external factors are eliminated either completely or partly, depending on the degree of recirculation and the construction of the plant.

Recirculation enables the fish farmer to completely control all the parameters in the production, and the skills of the farmer to operate the recirculation system itself becomes just as important as his ability to take care of the fish.

Controlling parameters such as water temperature, oxygen levels, or daylight for that matter, gives stable and optimal conditions for the fish, which again gives less stress and better growth **(Fig. 6).** These stable conditions result in a steady and foreseeable growth pattern that enables the farmer to precisely predict when the fish will have reached a certain stage or size. The major advantage of this feature is that a precise production plan can be drawn up and that the exact time the fish will be ready for sale can be predicted. This favours the overall management of the farm and strengthens the ability to market the fish in a competitive way.

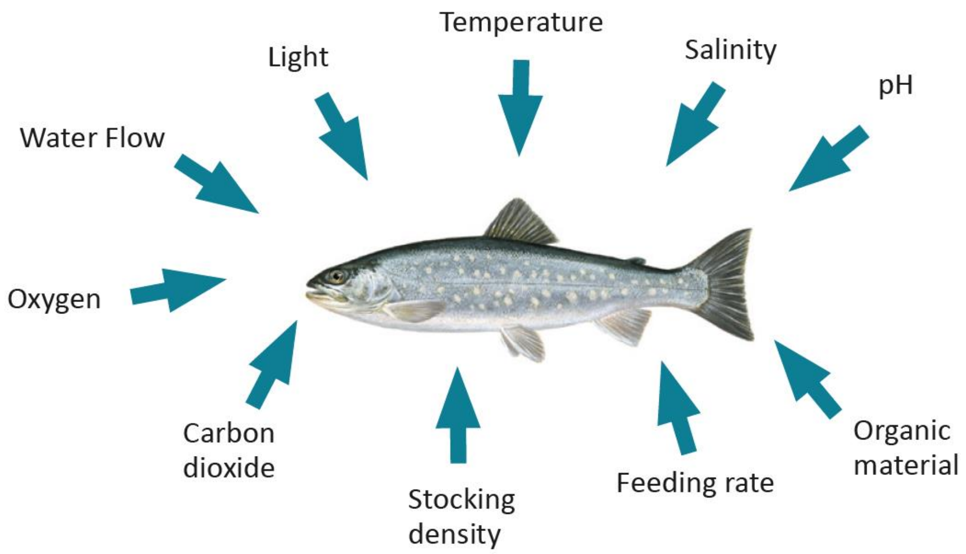


Figure 6: Parameters affecting the growth and well-being of a fish.

The impact of pathogens is lowered considerably in a recirculation system as invasive diseases from the outside environment are minimized by the limited use of water. Water for traditional fish farming is taken from a river, a lake or the sea which naturally increases the risk of dragging in diseases. Many recirculation systems do not have any problems with diseases whatsoever, and the use of medicine is therefore reduced significantly for the benefit of the production and the environment.

The Recirculation System: Step-by-step

In a recirculation system it is necessary to treat the water continuously to remove the waste products excreted by the fish, and to add oxygen to keep the fish alive and well. A recirculation system is in fact quite simple. From the outlet of the fish tanks the water flows to a mechanical filter and further on to a biological filter before it is aerated and stripped of carbon dioxide and returned to the fish tanks **(Fig. 7).** This is the basic principle of recirculation.

Several other facilities can be added, such as oxygenation with pure oxygen, ultraviolet light or ozone disinfection, automatic pH regulation, heat exchanging, denitrification, etc. depending on the exact requirements.

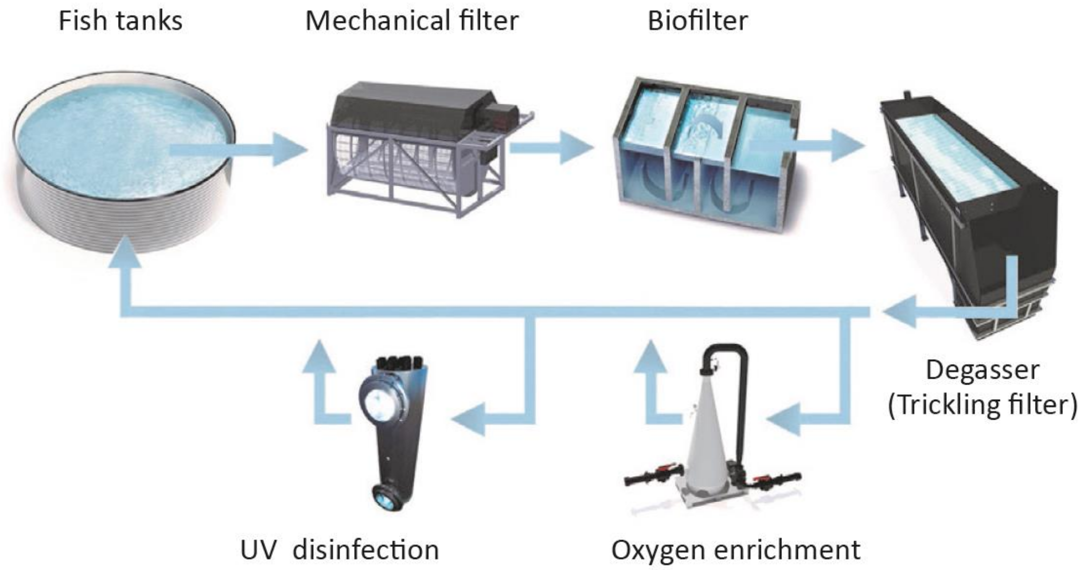


Figure 7: Principle drawing of a recirculation system.

Fish in a fish farm require feeding several times a day. The feed is eaten and digested by the fish and is used in the fish metabolism supplying energy and nourishment for growth and other physiological processes. Oxygen (O2) enters through the gills, and is needed to produce energy and to break down protein, whereby carbon dioxide (CO2) and ammonia (NH3) are produced as waste products. Undigested feed is excreted into the water as faeces, termed suspended solids (SS) and organic matter. Carbon dioxide and ammonia are excreted from the gills into the water. Thus fish consume oxygen and feed, and as a result the water in the system is polluted with faeces, carbon dioxide and ammonia **(Fig. 8).**

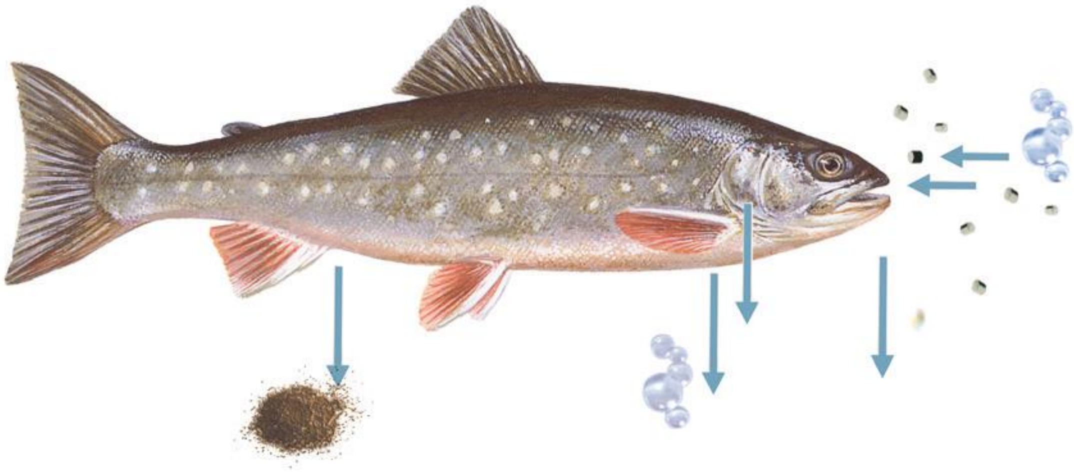


Figure 8: Eating feed and using oxygen results in fish growth and excretion of waste products, such as carbon dioxide, ammonia and faeces.

Only dry feed can be recommended for use in a recirculation system. The use of trash fish in any form must be avoided as it will pollute the system heavily and infection with diseases is very likely. The use of dry feed is safe and also has the advantage of being designed to meet the exact biological needs of the fish. Dry feed is delivered in different pellet sizes suitable for any fish stage, and the ingredients in dry fish feed can be combined to develop special feeds for fry, brood stock, grow-out, etc.

In a recirculation system, a high utilization rate of the feed is beneficial as this will minimise the amount of excretion products thus lowering the impact on the water treatment system. In a professionally managed system, all the feed added will be eaten keeping the amount of uneaten feed to a minimum. The feed conversion rate (FCR), describing how many kilos of feed you use for every kilo of fish you produce, is improved, and the farmer gets a higher production yield and a lower impact on the filter system. Uneaten feed is a waste of money and results in an unnecessary load on the filter system. It should be noted that feeds especially suitable for use in recirculation systems are available. The composition of such feeds aims at maximising the uptake of protein in the fish thus minimising the excretion of ammonia into the water.

Components in a Recirculation System

i) Fish Tanks

The environment in the fish rearing tank must meet the needs of the fish, both in respect of water quality and tank design. Choosing the right tank design, such as size and shape, water depth, self-cleaning ability, etc. can have a considerable impact on the performance of the species reared **(Table 5).**

In a circular tank, or in a square tank with cut corners, the water moves in a circular pattern making the whole water column of the tank move around the centre. The organic particles have a relatively short residence time of a few minutes, depending on tank size, due to this hydraulic pattern that gives a self-cleaning effect. A vertical inlet with horizontal adjustment is an efficient way of controlling the current in such tanks.

In a raceway the hydraulics have no positive effect on the removal of the particles. On the other hand, if a fish tank is stocked efficiently with fish, the self-cleaning effect of the tank design will depend more on the fish activity than on the tank design. The inclination of the tank bottom has little or no influence on the self-cleaning effect, but it will make complete draining easier when the tank is emptied.

Table 5: Different tank designs give different properties and advantages. Rating 1-5, where 5 is the best.

Tank properties	Circular tank	D-ended raceway	Raceway type
Self-cleaning effect	5	4	3
Low residence time of particles	5	4	3
Oxygen control and regulation	5	5	4
Space utilization	2	4	5

Circular tanks take up more space compared to raceways, which adds to the cost of constructing a building. By cutting off the corners of a square tank an octagonal tank design appears, which will give better space utilization than circular tanks, and at the same time the positive hydraulic effects of the circular tank are achieved. It is important to note that construction of large tanks will always favour the circular tank as this is the strongest design and the cheapest way of making a tank.

A hybrid tank type between the circular tank and the raceway called a "D-ended raceway" also combines the self-cleaning effect of the circular tank with the efficient space utilization of the raceway **(Fig. 9).** However, in practice this type of tank is seldom used, presumably because the installation of the tank requires extra work and new routines in management.

Sufficient oxygen levels for fish welfare are important in fish farming and are usually kept high by increasing the oxygen level in the inlet water to the tank.

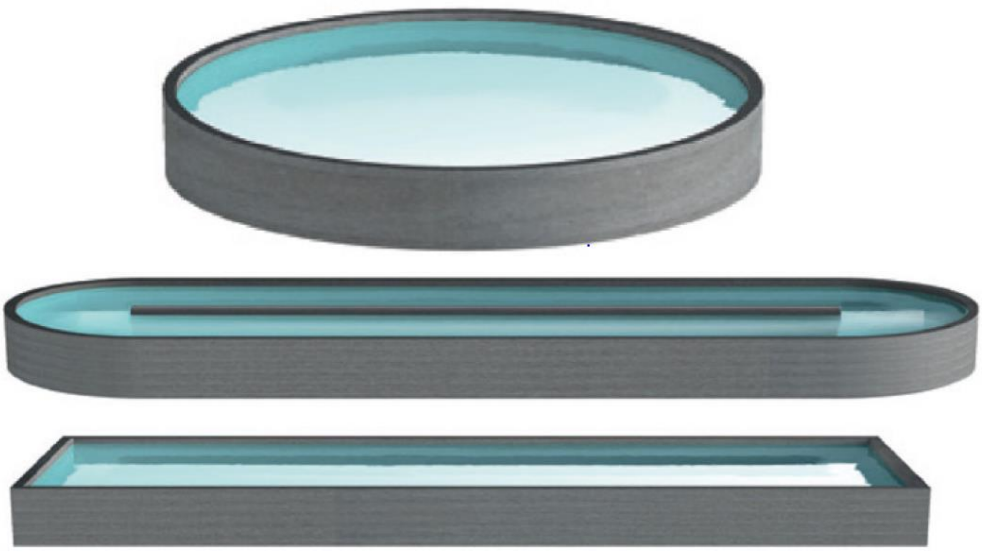


Figure 9: Circular tank, D-ended raceway and raceway type.

ii) Fish Species in Recirculation

A recirculation system is a costly affair to build and to operate. There is competition on markets for fish and production must be efficient in order to make a profit. Selecting the right species to produce and constructing a well-functioning system are therefore of high importance. Essentially, the aim is to sell the fish at a high price and at the same time keep the production cost at the lowest possible level.

Water temperature is one of the most important parameters when looking at the feasibility of fish farming, because fish are cold blooded animals (**Fig. 10).** This means that fish have the same body temperature as the temperature of the surrounding water. Fish cannot regulate their body temperature like pigs, cows or other farmed animals.

Certain fish simply do not grow well when the water is cold; the warmer the water, the better the growth. However, different species have different growth rates depending on the water temperature, and fish also have upper and lower lethal temperature limits. For Atlantic salmon, silver cob and yellowtail kingklip the ideal water temperature range is 12 to 16ºC.

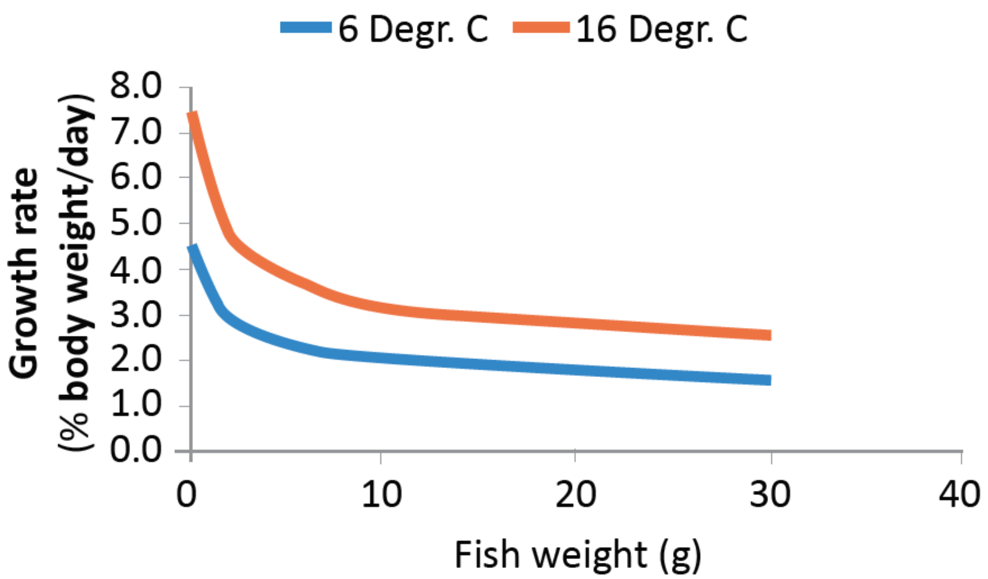


Figure 10: Growth rate of rainbow trout at 6 degrees and at 16 degrees Celsius as function of fish size.

Another issue affecting the feasibility of fish farming is the size of the fish grown in the farm. At any given temperature, small fish have a higher growth rate than large fish. This means that small fish are able to gain more weight over the same period of time than large fish **(Fig. 10).**

Small fish also convert fish feed at a better rate than large fish. Growing faster and utilising feed more efficiently will of course have a positive influence on the production costs as these are lowered when calculated per kilogram of fish produced. However, the production of small fish is just one step in the whole production process through to marketable fish. Naturally, not all fish produced in fish farming can be small fish, and the potential for growing small fish is therefore limited. Nevertheless, when discussing what kind of fish to produce in recirculation systems, the answer, first and foremost, will be small fish. It simply makes sense to invest money in fry production, because you get more out of your investment when farming small fish.

Looking at the world production volume of farmed fish, the picture is not in favour of a multi species output. From **Fig. 11,** it can be seen that carp, of which we are only talking of some 5 different sub-species, is by far the most dominant. Salmon and trout are next in line, and this is only two species. The rest amounts to some ten species. One therefore has to realize that although there are plenty of species to be cultured, only a few of these go on to become real successes on a world-wide scale. However, this does not mean that all the new fish species introduced to aquaculture are failures. One just has to realize that the world production volume of new species is limited, and that the success and failures of growing these species depend very much on market conditions. Producing a small volume of a prestigious fish species may well be profitable as it fetches a high price. However, because the market for prestigious species is limited, the price may soon go down if production and thereby availability of the product rises. It can be very profitable to be the first and only one on the market with a new species in aquaculture. On the other hand, it is also a risky business with a high degree of uncertainty in both production and in market development.

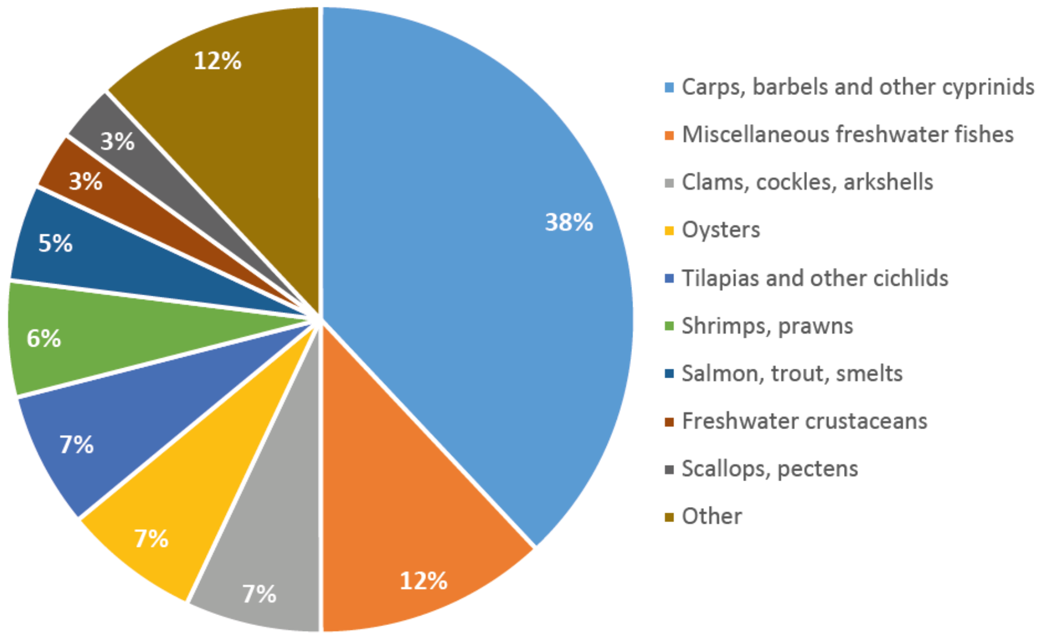


Figure 11: Distribution of global farmed seafood production in 2013. Source: FAO.

When introducing new species in aquaculture it should also be remembered that it is wild species, which are being captured and tested in aquaculture. Domestication is most often a long and troublesome task. There are many impacts, which will influence growth performance, such as high genetic variation in growth rate, feed conversation rate, survival rate and problems with early maturation and disease susceptibility. Thus, it is very likely that the performance of fish from the wild does not correspond to the expectations of the aquaculturist.

To give general recommendations on which species to culture in recirculation systems is not an easy task. Many factors influence the success of a fish farming business. For example, local building costs, cost and stability of electricity supply, availability of skilled personnel, etc. Two important questions though should be asked before anything else is discussed:

- does the fish species being considered have the ability to perform well in a recirculation facility and
- secondly is there a market for this species that will fetch a price high enough and at volumes large enough to make the project profitable.

The first question can be answered in a relatively simple manner: seen from a biological point of view, any type of fish reared successfully in traditional aquaculture can just as easily be reared in recirculation. As mentioned, the environment inside the recirculated fish farm can be adjusted to match the exact needs of the species reared. The recirculation technology in itself is not an obstacle to any new species introduced. The fish will grow just as well, and often even better, in a recirculation unit. Whether it will perform well from an economic point of view is more uncertain as this depends on the market conditions, the investment and the production costs and the ability of the species to grow rapidly. Rearing fish with generally low growth rates, such as extreme cold water species, makes it difficult to produce a yearly output that justifies the investment made in the facility.

It has always been recommended to use recirculation systems to produce expensive fish, because a high selling price leaves room for higher production costs. A good example is the eel farming business where a high selling price allows relatively high production costs. On the other hand, there is a strong tendency to use recirculation systems also for lower priced fish species such as trout or salmon.

The Danish recirculation trout farm concept is a good example of recirculation systems entering a relatively low price segment such as portion sized trout. However, it is necessary for such production systems to be huge, operating in volumes from 1 000 tonnes and upwards, in order to be competitive. In the future, perhaps in some areas growing large salmon will move from sea cage farming to land-based recirculation facilities for environmental reasons. Even an extremely low priced fish product such as tilapia will probably become profitable to grow in some kind of recirculation system as the fight for water and space intensifies.

The suitability of rearing specific fish species in recirculation depends on many different factors, such as the profitability, environmental concerns, biological suitability. In the tables below fish species have been grouped into different categories depending on the commercial feasibility of growing them in a recirculation system.

It should be mentioned that for small fish the use of recirculation is always recommended, because small fish grow faster and are therefore particularly suited to a controlled environment until they have reached the size for on-growing.

Good biological performance and acceptable market conditions make the following fish interesting for production to market size in recirculation aquaculture:

iii) Waste Water Treatment

Farming fish in a recirculation system where the water is constantly reused does not make the waste from the fish production disappear **(Fig. 12).** Dirt or excretions from the fish still have to end somewhere.

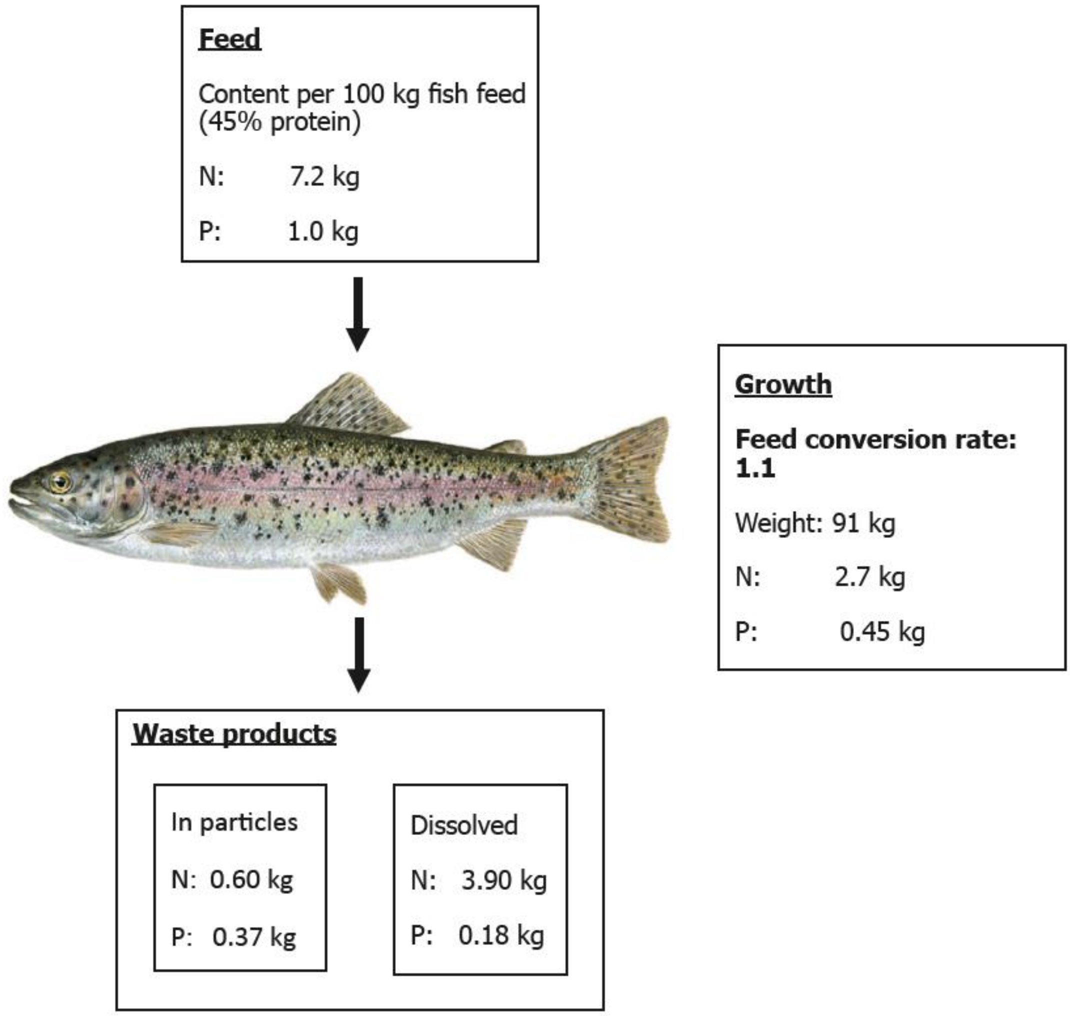


Figure 8: Excretion of nitrogen (N) and phosphorus (P) from farmed fish. Note the amount of N excreted as dissolved matter. Source: Biomar and the Environmental Protection Agency, Denmark.

The biological processes within the RAS will in a smaller scale reduce the amount of organic compounds, because of simple biological degradation or mineralization within the system. However, a significant load of organic sludge from the RAS will still have to be dealt with **(Fig. 13).**

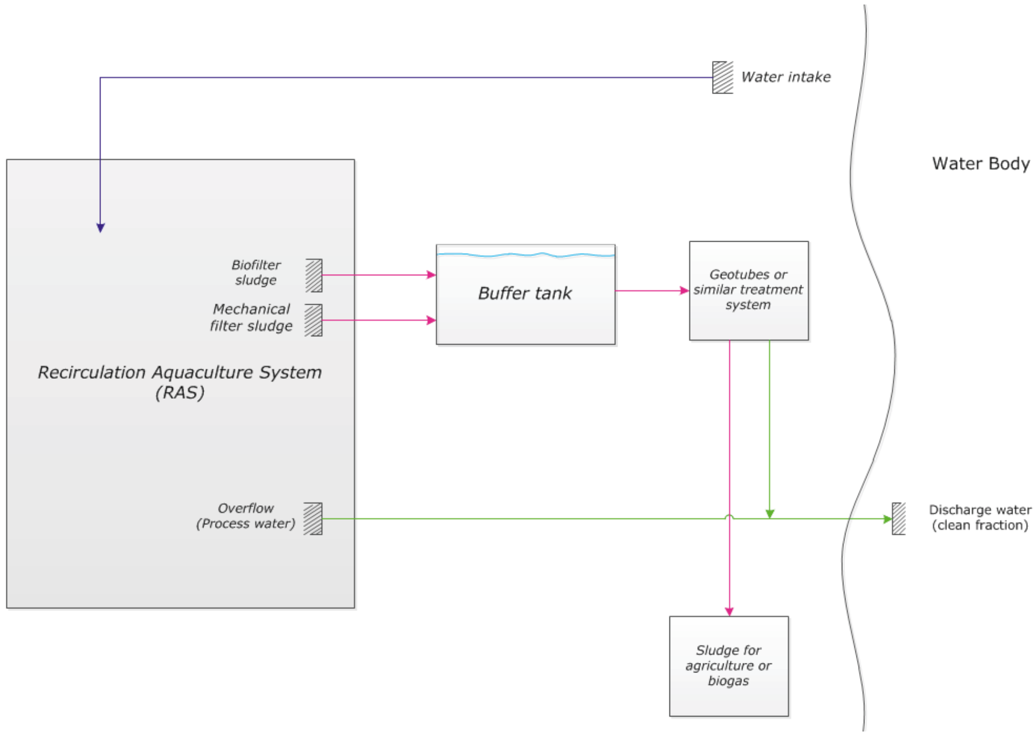


Figure 9: Sketch of flows to and from a recirculation aquaculture system.

Most RAS will have an overflow of process water for balancing the water going in and out of the system. This water is the same water as the fish are swimming in, and is as such not a pollutant unless the discharged amount of water from the overflow is excessive and the yearly discharge through this point escalates. The more intensive the rate of recirculation, the less water will be discharged through the overflow.

The waste water leaving the recirculation process typically comes from the mechanical filter, where faeces and other organic matters are separated into the sludge outlet of the filter. Cleaning and flushing biofilters also adds to the total waste water volume from the recirculation cycle.

Treating the waste water leaving the RAS can be accomplished in different ways **(Fig. 14).** Quite often a buffer tank is installed prior to the sludge treatment system where sludge is separated from the discharge water. Sludge will go to an accumulation facility for sedimentation or further mechanical dewatering, before it is spread on land, typically as fertilizer and soil improvement on agricultural farms, or it can be used in biogas production for generating heat or electricity. Mechanical dewatering also makes the sludge easier to handle and minimizes the volume whereby disposal or possible fees becomes cheaper.

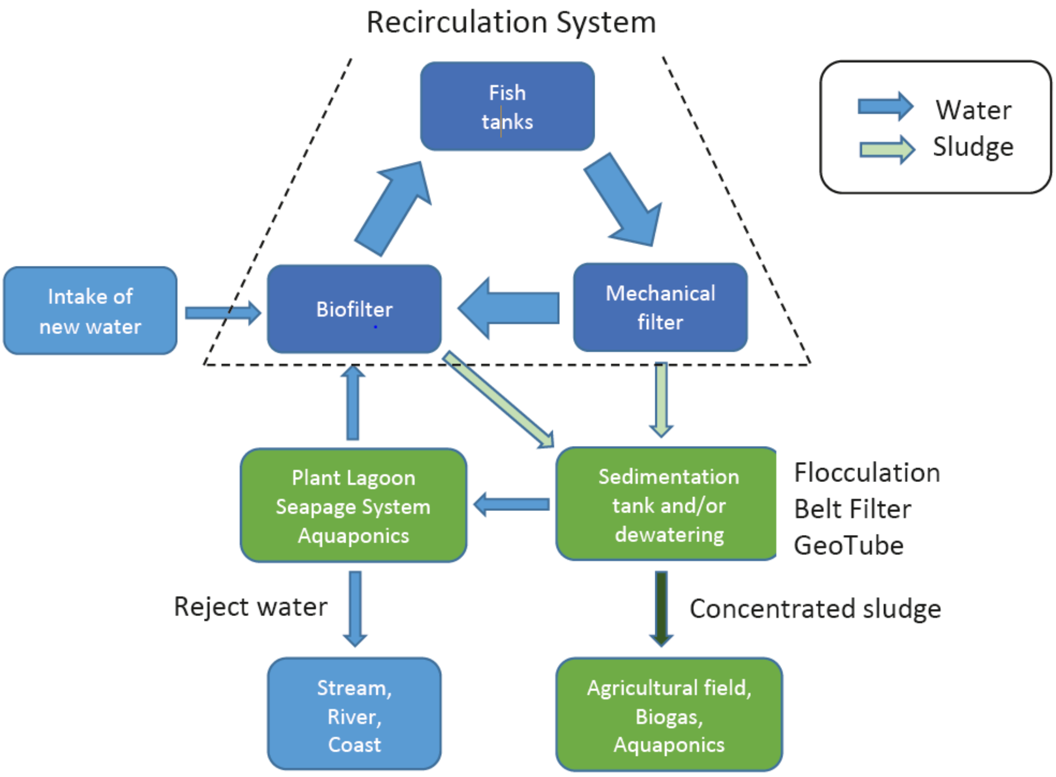


Figure 10: The pathways of sludge and water inside and outside a recirculation system. The higher the rate of recirculate on, the lower the amount of water let out from the system (dotted line), and the lower the amount of waste water to be treated. Source: Hydrotech.

The cleaned waste water from the sludge treatment will usually have a high concentration of nitrogen, whereas the phosphorus can be almost removed completely in the sludge treatment process. This discharge water is called reject water, and is most often discharged to the surroundings, river, sea, etc. together with the overflow water from the RAS. The content of nutrients in the reject water and in the overflow water can be removed by directing it to a plant lagoon, root zone or seepage system, where remaining phosphorous and nitrogenous compounds can be further reduced.

As an alternative, the reject water can be used as fertilizer in aquaponics systems. Aquaponics are systems where the waste from the fish is used for growing vegetables, plants or herbs, typically inside greenhouses. For larger fish farming systems it is recommended that the sludge is used for agricultural land and biogas, whereas the reject water is used for the aquaponics as this is simpler to handle and adjust with regards to cultures in greenhouses.

The content of nitrogen in the discharge water can also be removed by denitrification. As described, methanol is most commonly used as the carbon source for this anaerobic process, which transforms nitrate to free nitrogen to the atmosphere thus removing the nitrate from the reject water. Denitrification can also be used inside the recirculation system to reduce the amount of nitrate in the RAS process water in order to reduce the nitrate concentration, thus minimizing the need for new water in the system.

The use of denitrification outside the recirculation system is carried out in order to reduce the discharge of nitrogen into the environment. As an alternative to the use of methanol, the reject water coming from the sludge treatment system can be used as the carbon source. Using reject water as carbon source requires tight management of the denitrification chamber, and back-washing and cleaning the chamber can become more difficult. In any case, an efficient denitrification system can reduce the nitrogen content in the effluent water significantly.

It should be noted that fish excrete waste in a different way than other animals such as pigs or cows. Nitrogen is mainly excreted as urine via the gills, while a smaller part is excreted with faeces from the anus. Phosphorous is excreted with the faeces only. The main fraction of the nitrogen is therefore dissolved completely in the water and cannot be removed in the mechanical filter.

The removal of faeces in the mechanical filter will catch a smaller part of the nitrogen fixed in the faeces, and to a larger extent the amount of phosphorous. The remaining dissolved nitrogen in the water will be converted in the biofilter mainly to nitrate. In this form nitrogen is readily taken up by plants and can be used as fertilizer in agriculture or simply be removed in plant lagoons or root zone systems **(Table 6).**

Table 6: Removal of nitrogen (N), phosphorus (P) and suspended solids (SS) from mechanical filter. Source: Fisheries Research Station of Baden-Württemberg, Germany.

Parameter	Raceway	Raceway	Raceway	Self cleaning tank	Self cleaning tank	Self cleaning tank
	40 µ	60 µ	90 µ	40 µ	60 µ	90 µ
	Efficiency, %	Efficiency, %	Efficiency, %	Efficiency, %	Efficiency, %	Efficiency, %
Tot-P	50-75	40-70	35-65	65-84	50-80	45-75
Tot-N	20-25	15-25	10-20	25-32	20-27	15-22
TSS	50-80	45-75	35-70	60-91	55-85	50-80

Faeces from the fish tanks should flow immediately to the mechanical filter without being crushed on the way. The more intact and solid the faeces are, the higher the level of removed solids and other compounds. Figure 6.7 shows the estimated removal of nitrogen, phosphorous and suspended solids (organic matter) in a mechanical filter of 50 micron.

The higher the rate of recirculation the less new water will be used, and the less discharge water will need to be treated. In some cases, no water at all will return to the surrounding environment. However, this kind of “zero discharge” fish farming is costly to build and the running costs for the waste treatment are significant. Also, daily operation of the waste treatment will require significant attention to make it work efficiently. For zero-discharge fish farming one should also be aware that a certain amount of water exchange is always needed to prevent the accumulation of metals and phosphorous compounds in the system.

The bottom line is that authorities and the fish farmer must agree on a discharge permission that allows protecting the environment whilst having an economical viable fish farming business.

Combining intensive fish farming, whether recirculation or traditional, with extensive aquaculture systems, such as for example traditional carp culture, can be an easy way to handle biological waste. The nutrients from the intensive system are used as fertilizer in the extensive ponds when the excess water from the intensive farm flows to the carp pond area. Water from the extensive pond area can be reused as process water in the intensive farm. Growth of algae and water plants in the extensive ponds will be eaten by the herbivorous carp, which in the end are harvested and used for consumption. Efficient rearing conditions are obtained in the intensive system and the environmental impact has been accounted for in combination with the extensive pond area.

iv) Disease

For the innovative entrepreneur there are several opportunities in this kind of recycled aquaculture. The example of combining different farming systems can be developed further into recreational businesses, where sport fishing for carp or put & take fishing for trout can be part of a larger tourist attraction including hotels, fish restaurants and other facilities.

There are many examples of recirculation systems operating without any disease problems at all. In fact, it is possible to isolate a recirculation fish farm completely from unwanted fish pathogens. Most important is to make sure that eggs or fish stocked in the facility are absolutely disease free and preferably from a certified disease free strain. Make sure that the water used is disease free or sterilized before going into the system; it is far better to use water from a borehole, a well, or a similar source than to use water coming directly from the sea, river or lake. Also, make sure that no one entering the farm is bringing in any diseases, whether they are visitors or staff **(Fig. 15).**

Whenever possible, a thorough disinfection of the system should be carried out. This includes any new facility ready for the very first start-up as well as for any existing system that has been emptied of fish and is ready for a new production cycle. It should be remembered, that a disease in one tank of a recirculation system will most certainly spread to all the other tanks in the system, which is why preventive measures are so important.

Figure11: Foot bath with 2 % iodine solution for preventing the spread of disease.

In recirculation systems using eggs from wild fish, for example for the purpose of re-stocking, getting eggs from certified disease free strains is not possible. In such cases, there will always be a risk of introducing diseases living inside the egg, such as IPN (Infectious Pancreas Necrosis), BKD (Bacterial Kidney Disease) and possibly herpes virus, which cannot be eliminated by disinfecting the eggs. An example of a prevention scheme is shown in **Table 7.**

A good way to prevent contamination with pathogens within the system is to physically separate the different stages in the production. The hatchery should therefore work as an isolated closed system, as should the fry unit and the grow-out unit. If any brood stock is kept, this should also be isolated in a unit of its own. This way, stamping out a disease becomes easier to carry out in practice.

Table 7: An example of a prevention scheme.

What to remember	How is it done?
Clean source of new water	Preferably use ground water. Disinfect using UV. In some cases use sand filter and ozone.
Disinfection of system	Fill system with water and bring pH up to 11-12 by the use of sodium hydroxide NaOH. Approximately 1 kg per m^3 water volume depending on buffer capacity.
Disinfection of equipment and surfaces	Dip or spray with an iodine solution of 1.5% or according to instructions. Leave for 20 minutes before wash off in clean water.
Disinfection of eggs	Leave egg batch (eyed rainbow trout eggs) in solution of 3 dl of iodine per 50 litres of water for 10 minutes. Change solution for every 50 kg eggs disinfected.
Staff	Change clothing and foot wear when entering facility. Wash or disinfect hands.
Visitors	Change of foot wear or use footbath for dipping shoes (2 % iodine solution). Wash or disinfect hands. "Do not touch" policy for visitors inside the facility.

Some farms have been constructed after the "all in all out" principle, meaning that each unit is emptied completely and disinfected before new eggs or fish are stocked. For eggs and smaller fish, which are grown over a shorter period of time before they are moved on, this is certainly good management, and should always be carried out in practice **(Fig. 16).** For larger fish this is also good practice, however this kind of management easily becomes inefficient. Taking all the fish out of a grow-out unit before stocking a new batch, is logistically difficult when dealing with large volumes of fish. It easily becomes uneconomical, because of inefficient utilization of the capacity of the system.

Treating fish diseases in a recirculation system is different from treating them on a traditional fish farm. On a traditional fish farm, the water is used only once before leaving the farm. In a recirculation system, the use of biofilters and the constant recycling of water calls for a different approach. Pouring in medication will affect the whole system including fish and biofilters, and great care must be taken when treatment is carried out. It is very difficult to give exact prescriptions on the dose needed to cure a disease in a recirculation system, because the effect of the medication depends on many different parameters such as hardness of water, content of organic matter, water temperature and flow rates. A great deal of practical experience is therefore the only way forward. Concentrations must be increased carefully from each treatment to the next to avoid killing the fish or the biofilter. Always remember the term "better safe than sorry". In any case of a disease outbreak, a local veterinarian or fish pathologist must prescribe the medication and explain how to use it. Also, the safety instructions should be read carefully as some drugs may cause severe injuries to people if used improperly.

Figure 16: Disinfecting fish eggs prior placing them into the quarantine recirculation system Source: Torben Nielsen, AquaSearch Ova.

Treatment against ecto-parasites, which are parasites sitting on the outside of the fish on the skin and in the gills, can be carried out by adding chemicals to the water. Any fungal infections will have to be treated in the same way as infestations with ecto-parasites. In freshwater systems the use of ordinary salt (NaCl) is an efficient way of killing most parasites including bacterial gill disease. If a cure with salt does not work, the use of formalin (HCHO) or hydrogen peroxide (H2O2) will usually be sufficient to cure any remaining parasitic infections. Bathing fish in a solution of praziquantel and flubendazol have also proven to be very efficient against ectoparasites.

Mechanical filtration has also proven to be quite efficient against the spreading of ecto-parasites. Using a filter cloth of 70 micron will remove certain stages of Gyrodactylus, and a 40 micron cloth can remove different kinds of parasite eggs.

The safest way of carrying out a treatment is to dip the fish in a bath with a solution of the chemical. However, in practice this is not a feasible method as the volume of fish that needs to be handled is often too large. Instead fish are kept in the tank as the inlet water is switched off, and oxygenation or aeration of the tank is carried out by the use of diffusers. A solution of the chemical is added to the tank and the fish are allowed to swim in the mixture for a period of time. Later, the inlet water is opened, and the mixture slowly diluted as the water in the tank is exchanged. The water running out from the tank will be diluted by the rest of the recirculation system so that the concentration in the biofilter will be significantly lower than in the tank treated. This way a relatively high concentration of the chemical can be obtained in an individual tank with the purpose of killing the parasite, yet lowering the effect of the chemical on the biofilter system.

Both fish and biofilters can adapt to treatment with salt, formalin and hydrogen peroxide by slowly increasing the concentrations from one treatment to the next. When a tank full of fish has been treated, this water can also be pumped out of the system to a separate compartment for degradation instead of being recirculated in the system.

Using the dipping technique for eggs is an easy way of treating millions of individuals in a short time, for example when disinfecting trout eggs in iodine (figure 15). This method can also be used for treating eggs that have been infected with fungus (Saprolegnia) simply by dipping the eggs into a solution of salt (7 ‰) for 20 minutes.

In hatcheries, where fish are removed as soon as they are ready to feed, the efficiency of the biofilter is less important as the level of ammonia excreted from eggs and fry is very little. Treatment is therefore easier to carry out, because one only has to focus on the survival of eggs and fish. Also, it is worth noting that the total volume of water in a hatchery is small, and a complete water exchange with new water can be carried out rapidly. Therefore, a successful treatment in a hatchery by treating the whole system in one go, can be done safely.

Treatment of a complete system in larger recirculation facilities is a more sensitive operation. The basic rule is to keep concentrations low, and to carry out the treatment over a longer period of time. This requires care and experience. The concentration should be slowly increased from each treatment to the next, leaving several days in between without treatment in order to carefully monitor the effects on fish mortality, behaviour and water quality. Typically, an adaptation will take place for both fish and biofilter, so the concentration can be increased with no adverse effects and the probability of killing the parasite is enhanced. Salt is excellent for longer treatment periods, but formalin too has been successfully used for intervals of 4-6 hours. The biofilter simply adapts to the formalin and digests the substance like any other carbon coming from the organic compounds in the system.

As pointed out previously, it is not possible to give exact concentrations and recommendations on the use of chemicals in a recirculation system. Fish species, size of fish, water temperature, hardness of water, the amount of organic substances, exchange rate of water, adaptation, etc. must all be taken into consideration. The guidelines below are therefore approximate:

Salt (NaCl): Salt is relatively safe to use, and can be used in fresh water for treating Ich (Ichthyophthirius multifilis or white spot disease) and the common fungus saprolegnia. Ich in the pelagic phase can be killed at 10 ‰ and new results suggests killing of the bottom living stages at 15 ‰. Fish contains around 8 ‰ salt in their body fluids, and most freshwater fish will tolerate salinities in the water around this level for several weeks. In hatcheries a concentration of 3-5 ‰ will prevent infections with fungus.

Formalin (HCHO): Low concentrations of formalin (15 mg/L) for long periods of time (4-6 hours) have shown good results in the treatment of Ichthyobodo necator (Costia), Trichodina sp., Gyrodactylus sp., sessile ciliates, and Ich. Formalin is degraded relatively fast in the biofilter at about 8mg/h/m^2 biofilter area at 15 ℃. Formalin can however reduce the bacterial nitrogen conversion rates in the biofilter.

Hydrogen peroxide (H_2O_2): Not widely used, but experiments have shown promising results as a substitute for formalin at concentrations between 8-15 mg/L for 4-6 hours. The biofilter performance can be inhibited for at least 24 hours after treatment, but the efficiency will return to normal within a few days.

Use of other chemicals such as copper sulphate or chloramin-t is not recommended. These are very effective for the treatment of for example bacterial gill disease, however the biofilter will most probably suffer severely and the whole recirculation process and the production may be seriously damaged.

For treatment against bacterial infections, such as furunculosis, vibriosis or BKD, the use of antibiotics is the only way to cure the fish. In some cases fish can become infected with parasites living inside the fish, and the way to remove these is also with antibiotics.

Antibiotics are mixed into the fish feed and fed to the fish several times every day over, for example, 7 or 10 days. The concentration of antibiotics must be sufficient to kill the bacteria, and the prescribed concentration of medication and the length of the treatment must be carefully followed, even if the fish stop dying during the treatment. If treatment is stopped before the prescribed treatment period, there is a high risk that the infection will start all over again.

Treatment with antibiotics in a recirculation system will have a small effect on the bacteria in the biofilter. However, the concentration of antibiotics in the water, compared to that inside the fish being treated with medicated feed, is relatively low, and the effect on bacteria in the biofilter will be much lower. In any case, one should carefully monitor the water quality parameters for any changes because they may indicate an effect on the biofilter. Adjustment of the feeding rate, use of more new water or changing the flow of water in the system may be necessary.

Several antibiotics can be used, such as sulfadiazine, trimethoprim or oxolinic acid according to the prescription by the local veterinarian.

Treatment against IPN, VHS (Viral Hemorrhagic Septicemia) or any other virus is not possible. The only way to get rid of viruses is to empty the whole fish farm, disinfect the system and start all over again.

v) Import of eggs / smolt / fry

The regulations for the import of live organisms as per the Import and Export regulation 2010 (MFMR) need to be followed, which includes the following:

- Clearance certificate of the exporting country that the organisms are disease free
- Clearance certificate of the host country
- Organisms to be kept in quarantine (onshore) between 1 to 3 months until such a date that the Veterinary department clears the consignment as disease free

vi) Future of Recirculation

Pre on-growing of fish in recirculation systems to reach larger sizes before releasing them into the sea cages is a way of increasing profitability. The Norwegian salmon farming industry is investing in large recirculation facilities with the aim of producing smolt to larger sizes. Smolts are typically 100 gram today when released in cages. An increase to 300 gram before stocking will improve health and growth rates significantly in the farming period until harvest at market size of typically 4-5 kg.

7.2 Offshore facilities and activities

For the initial operation, a total of three cluster cages will be installed. The three cluster cages will be deployed in two (2) Phases with each comprising of 4 sub-units in Phase 1 and 6 sub-units in Phase 2 for each fish species as illustrated in **Fig. 17** and **Fig. 18.**

More detail on farm design layout offshore, is presented in the EIA report which includes:

- ➢ Deployment
- ➢ Operation
- ➢ Maintenance

Figure 12: View of the offshore farm layout for 4x fin fish cages in Phase 1 of construction (BW FishFarm, 2020).

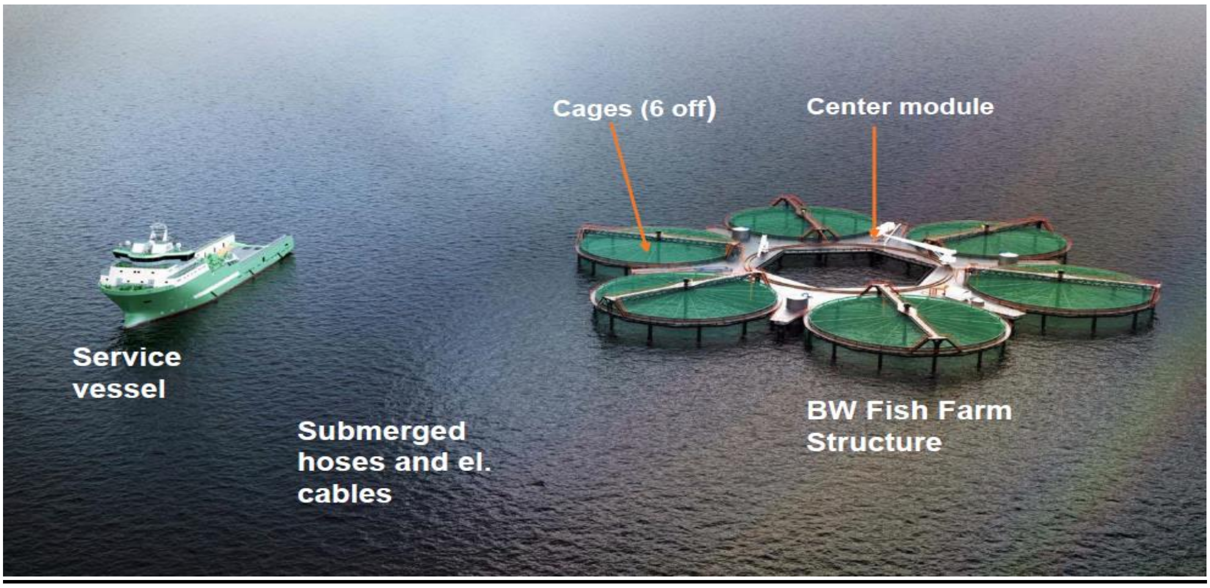


Figure 18: Bird's view of the offshore farm layout for 6x fin fish cages in Phase 2 (BW FishFarm, 2020).

Navigational Buoys

The first components that are to be installed are the marker buoys that designate the farm perimeter as per the ECC and aquaculture licence. One marker buoy is placed on each corner of the farm site **(Fig. 19a & b).** The GPS for each marker buoy need to be communicated to Lüderitz Port-control which will be inserted on the marine navigational maps.

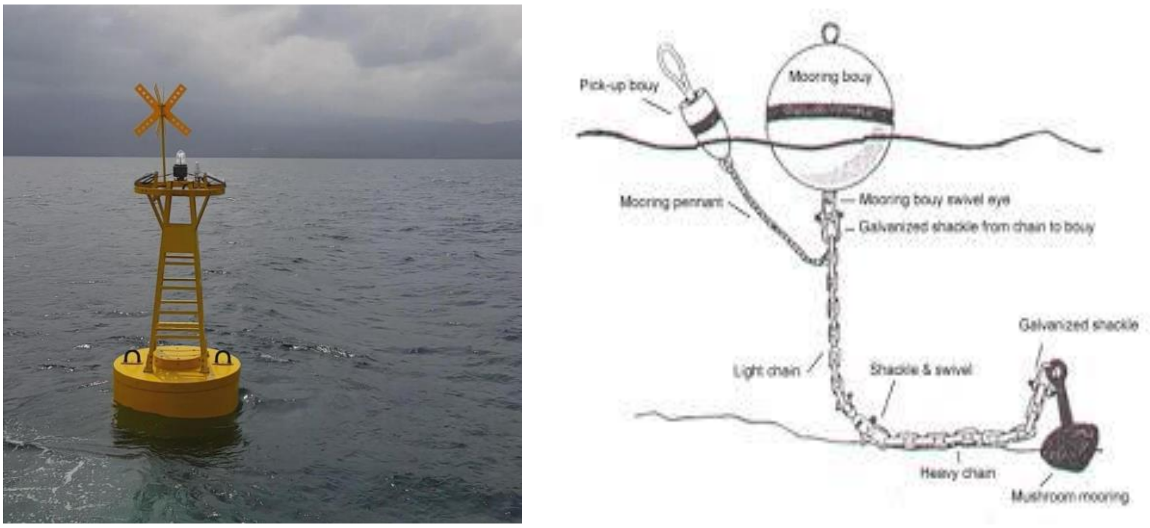


Figure 19a & b: LHS a typical marker buoy and on RHS the mooring anchored to the seafloor with concrete slab.

Potential negative impacts can include:
Impacts are to be expected, however, as stated by Jacques Cousteau (1910-1997) "We must plant the sea and herd its animals using the sea as farmers instead of hunters. That is what civilization is all about - farming replacing hunting". Potential Impacts may include **(Fig. 20):**

- Fish Feed (nutrients and vaccines)
    - Local nutrient pollution into water systems from waste feed/faeces.
    - Local chemical pollution through use of chemical treatments.
- Suspended fish cages
    - Obstructs potential whale and dolphin migration routes
    - Attract predators: birds/seals/sharks
- Escapees
    - Effect on wild fish of escapees, through the spread of diseases, competition for food, space, and breeding partners, and genetic introgression.
- Pathogens
    - Transmission of ectoparasites (especially sea lice, which are species of copepod in the genera *Lepeophtheirus* and *Caligus*) from farmed fish to wild fish
- Eutrophication
    - Excess feed - nutrient pollution into water systems from waste feed/faeces.

Mitigation
The FAO guidelines (2014), published various Technical Reports on: Introducing the Best Aquaculture Practices (BAP) to be adopted (and enforced) by governments which will minimize potential impacts.
Good aquacultural **practices** (GAqPs) are activities, procedures, or considerations that maximize environmental and economic sustainability, product quality and safety, animal health, and worker safety, while also minimizing the likelihood of a disease outbreak on the farm. Namibia has Acts and Regulations in place to mitigate the above potential impacts

i) The Ministry of Agriculture, Water and Land Reform have procedures in place to ensure that:
    - Only certified fish feed may be imported into Namibia and only
    - Registered vaccines may be used

ii) As per the Regulation on the Import and Export of aquatic organisms and aquaculture products the Ministry of Fisheries and Marine Resources (Govt. Notice 70 of 2010) all live imported aquatic organisms need to be quarantined for at least one month prior being released to the offshore cages.

iii) The daily feeding process will be monitored by camera and terminated once fish have stopped feeding, which will minimize feed waste.

iv) Any waste (faeces and feed) that may accumulateat the seabed will be flushed out by the strong prevailing north-westerly Benguela Current.

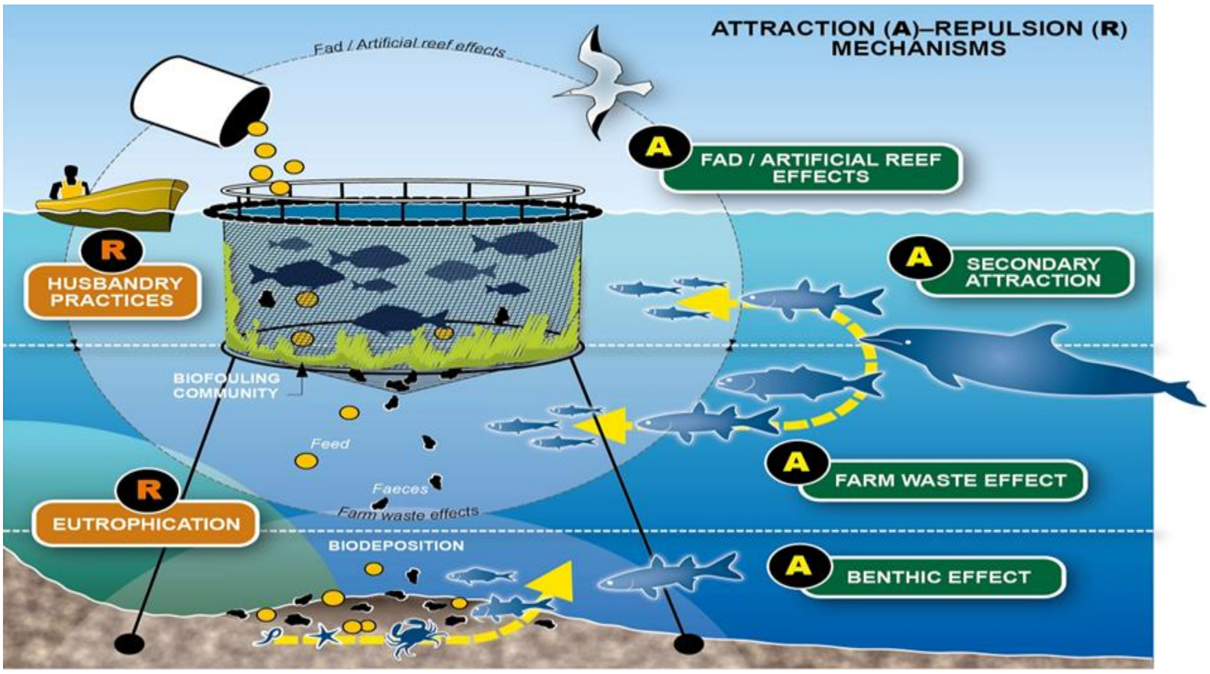


Figure 20: Schematic presentation of potential impacts for an offshore cage culture operation.

8. SCIO-ECONOMIC BENEFITS

The socio-economic responsibilities of Lilongeni Fish-Farming (Pty) Ltd includes the following:

- Labour compliance
  - To adhere to the Labour Act and Regulation
- Training
  - Staff to be provided with ongoing training (hands on) which will enhance productivity and lesson on site injuries
- Awareness
  - The public need to be kept abreast on activities taking place onshore as well as offshore
- Cooperate-social responsibility
  - Lilongeni is committed to assist in this regard as follows:

- Provide internships to UNAM mariculture students
- Make available MSc and PhD bursaries to students venturing into aquaculture

9. ENVIRONEMNATAL MONITORING PROGRAM

Monitoring of the environment offshore is to ensure and to enhance productivity and to act as an early warning system.

Protocols need to be in place for the EMP reporting system (Logbooks). The proposed operation of finfish cage farming north-west of Lüderitz, if not properly managed, can result in a variety of adverse environmental impacts that are mainly determined by the release of organic matter and nutrients, for example, those originating from faecal waste and uneaten fish feed.

The major activities that need to be monitored on a daily basis include fish health and monthly basis net and buoy anchorage

Furthermore, potential sources of impacts include the use of sub-standard feed, farmed fish escape events, and diseases outbreaks. The EMP need to be:

- flexible and adaptable, and
- take into account the scale (time and space) approach, as well as
- the type of facility, farming system and production levels

The EMP requires data on the “zero state” for all indicators and on defined limits of tolerance and requires the collection of a series of information on the particular area, and of data considered as most appropriate to describe the environmental conditions of the water and sediment. These should be registered in a logbook that will be referred to as the record-keeping system, which is intended to record:

- physical
- chemical and
- biological information

collected within the monitored areas, including the area located in the immediate vicinity of the finfish farm. The logbook should include:

- the frequency of sampling,
- the physical and
- chemical variables
- as well as the number and locations of the sampling stations relative to the locations of the fish cages.

According to FAO (2012), the record-keeping system should comprise two logbook types:

- logbook 1 (Lb1): refers to the area the finfish cages are deployed and
- logbook 2 (Lb2): refers to the monitoring activities undertaken within the zone surrounding the far.

Logbook 1 should contain at least the following information:

- Maps with locations of the fish farm, fish cages and monitoring stations
- Water depth (min, max, mean)
- Mean sea current speed
- Sediment grain size
- Information on the benthic community
- Information on sensitive habitats, if any
- Information on the finfish farm:
    - cages farming system and characteristics
    - cultured species and cycles production capacity
    - estimated feed conversion ratio (FCR)
    - potential maximum cultured biomass per year
    - potential maximum feed quantity used per year).

Logbook 2 should contain information that will be recorded during the monitoring activities (refer to Table 8):

- Weather conditions (wind speed and direction)
- Fish growth and Fish feed consumption (FCR)
- Water quality (sea temperature, oxygen levels)
- Sea physical parameters (wave height and current speed)

The sampling frequency will be determined which parameter is to be measured. The monitoring can be daily (e.g. sea surface temperatures, oxygen levels, net cages, bird and marine mammals sighted at the farm), weekly (e.g. buoy and net anchorage ropes), monthly (e.g. bio-fouling of nets), yearly (e.g. sediment accumulation below the nets) .

The number of sampling stations should be as follows:

- 2x control stations
- 1x under the cages
- 1x up-current located 50 m from the cages
- 1x down-current located 25 m from the cages
- 1x down-current located 50 m from the cages

The variables to be recorded in Logbook 2 should at least include the following physical, chemical and biological attributes:

- Sediment monitoring (below and surrounding cages)
- Temperature (°C)
- Macrobenthic community
- Salinity (psu) Visual inspection
- Turbidity (Secchi depth)
- Dissolved oxygen (% saturation; mg/l)
- Sulphide (µM)
- Chlorophyll a (mg/l)
- Organic matter (LOI, %)
- pH (unit)
- Ammonium (N-NO4, µM)
- Total Organic Carbon (TOC, %)
- Nitrite (N-NO2, µM)
- Total Nitrogen (µM)
- Nitrate (N-NO3, µM)
- Total Phosphorous (µM)
- Phosphate (P-PO4, µM)

At each station, samples will be collected at three different layers

- surface
- intermediate and
- seabed

There should also be some dedicated space to allow the recording of:

- Escapee incidents (species; size; number)
- Disease incidents (type of disease; species at risk; number of outbreaks; medical treatment used)
- Disasters and weather-related events (e.g. presence of jelly fish; mortalities caused by exogenous pollution; storm events, etc.)

In the Table 8a & b, below, a summary of the activities and potential impacts that will need to be monitored on a regular and continued basis onshore as well as offshore.

Table 8a: List of main parameters that need to be monitored onshore at the quarantine facility.

PARAMETER TO BE MONITORED	INTERVAL
Water quality (dissolved oxygen, temperature, pH, ammonia)	daily
Fish health (mortalities, diseases, any abnormalities)	daily

Feed stock (consumption in kg per day per species)	daily
Fish growth per species	weekly
Water quality (nitrites, nitrate, nitrogen, phosphates)	weekly
All weather station (wind speed, wind direction, air temperature and humidity)	daily

Table 8b: List of major parameters that need to be monitored offshore operation at surface, intermediate, bottom.

PARAMETER TO BE MONITORED	INTERVAL
Marine mammals sighted (species, time of day, numbers)	daily
Water quality (dissolved oxygen and temperature)	daily
Fish health (mortalities, diseases, any abnormalities)	daily
Feed stock (consumption in kg per day per species)	daily
Water quality (nitrite, phospahte)	weekly
Chlorophyll a (mg/l)	weekly
Net condition	daily
Buoy and net anchorge	monthly
Sedimentation accumulation on the seabed	annually
Net fouling	monthly
Fish growth per species	monthly
Current speed	daily
Wind direction and velocity	daily
Wave height	daily
Presence of jelly fish and algae setling on net cages	ongoing
Storm at sea	ongoing

In Appendix 1 and 2, two Tables are provided that can assist the Proponent in compiling a monitoring program which need to be in place prior the construction and operational phase.

Performance assessment

The Proponent need to provide the ED (Competent Authority – MFMR), as well as the EC (MEFT), bi-annual reports on:

i) Progress on the construction and maintenance phase and
ii) The operational stage both onshore and offshore

A staff member should be provided with this responsibility to compile such reports.

Financial provision

As per the annual budget an allocation of funds specifically for the votes, provision has been made for:

i) Vote: to cover the cost of the monitoring and

ii) Vote: to cover the -ve impacts of this project should they arise

Roles and Responsibilities

A summary of the roles and responsibilities is provided in Table 9, below.

Table 9: Summary of roles and main responsibilities for the implementation of the EMP.

Role	Responsibilities
Proponent	• Overall accountability for the EMP's implementation and management. • Responsible for providing the necessary resources (both financial and technical) to complete the tasks and put the EMP into action.
Farm Manager / Project manager	• Responsible for ensuring compliance with this EMP including overseeing the construction phase, day to day mariculture activities during operations, and routine and non-routine maintenance works during operations, as well as the decommissioning of the development. • Provisioning of environmental awareness/management training and inductions for all employees. • Ensuring that best environmental practice is undertaken throughout the duration of the project, • Report any non-compliance or accidents to the regulatory authority. • Ensuring all personnel are aware of the commitments made in this EMP and any other relevant regulatory requirements applicable to the project. • Responsible for the management, maintenance, and revisions of this EMP. • Ensuring adequate resources are made available for the implementation of this EMP. • keeping financial records, planning budgets, and carrying out a range of administrative duties.

Fish Biologist / Marine Biologist	• Responsible for regular health checks, and monitoring and managing biosecurity issues throughout the company's operations: - Managing quarantine facility - Managing the harvesting schedules - Monitoring the health of the fish - Training the farm staff who feed fish and clean holding tanks and nets - Making sure hygiene standards are high, to prevent diseases - Checking that the water quality and oxygen levels are optimum for the fish - Keeping records of the numbers and size of fish - Ordering equipment, chemicals, and fish feed - Arranging stock when ready to be harvested - Carrying out research - Ensure that logbooks are kept up to date
Fish veterinarian	• Appoint a 'marine' Vet for the project • Clinical responsibilities for fish stocks • Prevention of diseases through effective monitoring and biosecurity controls • Make final decisions regarding veterinary issues that may arise such as the requirement to treat and the appropriate type of treatment to be used
Fish Farmworkers	• Feeding fish by operating automatic feeding systems • Grading fish by size, moving them to bigger tanks or cages • Checking and maintaining water quality • Checking fish for disease, preventing, and treating infection • Draining and cleaning quarantine tanks, filters, and nets to prevent diseases • Repairing cages to avoid escapees • Fish processing • Maintaining buildings and equipment, involving basic joinery, plumbing and electrical work
Health and Safety officer	• Make sure that places of work are safe for workers and members of the public

	• Inspect machinery, management systems, working methods, and the use and storage of harmful substances and calculate associated risk factors. • Check that employers and employees follow health and safety regulations • Taking photos and measuring noise, temperature, and vibration levels • Warn employers or managers about bad practices and initiating enforced changes
Environmental Health Officer	• Deal with the safety of fish products to be produced at the proposed project • Help protect employees and the public in the town from disease and other dangers to health • Give advice and education on how to meet environmental health regulations and make sure that they are enforced
Environmental officer	• Oversee the environmental performance and work on improvements and sustainability of the proposed project. • Making sure the proposed project meets the targets for protecting the environment • Setting up environmental management and auditing systems for the proposed project • Ensure that the proposed project obeys environmental laws and applying for necessary licences or permits • Managing and checking environmental assessments and writing environmental reports • Ensuring that goods and services are sustainably produced as well as set sustainability targets for the project • Responsible for pollution control, recycling and biodiversity conservation • Assessing and reducing environmental risks and costs • Raising awareness of the environment among employees and running training courses

10. LEGAL FRAMEWORK AND COMPLIANCE

A summary of legislations and policies relevant to this proposed fin fish culture in cages offshore from Lüderitz, is provided in Table 10 below. It is crucial that the Proponent familiarize themselves with the regulatory framework in place to ensure they comply during the construction and operation phase of this development.

Table 10: Legal compliance requirement and the respective regulatory authority

Acts, Policies, or Regulations	Relevance	Regulatory Authority
Environmental Management Act No. 7 of 2007	To determine if an EIA and EMP are required for an envisaged development	EC office of MEFT
Environmental Impact Assessment Regulation of 2012	To determine the impacts and provide mitigation	EC office of MEFT
Aquaculture Act No. 18 of 2002	Provides the legal framework of promoting the aquaculture industry	MFMR Directorate of Aquaculture
Aquaculture Regulation (Licensing) of 2003	Compliance for farming with aquatic organisms	MFMR Directorate of Aquaculture
Marine Resource Act No. 27 of 2000.	Competent Authority guiding the EIA within the MFMR – protection of nursery grounds	MFMR Directorate of Resource Management
Import and Export Regulation of Aquatic Organisms and Products of 2010	Refers to quarantine facility for imported organisms	MFMR Directorate of Aquaculture
Namibia Island's Marine Protected Area No. 316 of 2012	Protection of Islands and rocks for endangered and vulnerable bird species	MFMR Directorate of Resource Management
Marine Traffic Act (No. 2 of 1981) (as amended by the	Marine (shipping lanes) traffic	Ministry of Works and Transport

Marine Traffic Amendment Act (No. 15 of 1991)		
Territorial Sea and Exclusive Economic Zone of Namibia Act 3 of 1990	Natural resource use	Ministry of Works and Transport
Dumping at Sea Control Act (No. 73 of 1980)	Emissions and nets	Ministry of Works and Transport
Water Act, 1956 (No. 54 of 1956), as amended	Abstraction from and discharge into the sea	Ministry of Agriculture, Water and Land Reform
Water Resource Management Act 11of 2013	Water use, water quality and effluents to water bodies	Ministry of Agriculture, Water and Land Reform
Public Health Act 36 of 1919 (as amended)	Export fish products and import of smolt	Ministry of health and Social Services
Labour Act, 2007 (No. 11 of 2007)	Socio-economics	Ministry of Labour, Industrial Relation and Employment Creation
Namibian Ports Authority Act (No. 2 of 1994) and Port Regulations	Harbour facilities to be used	Ministry of Works and Transport
Nature Conservation Amendment Act No.5 of 1996	Impact on biodiversity and protected areas	Ministry of Environment, Forestry and Tourism - MEFT
Pollution Control and Waste Management Bill (draft) 2003	Waste on water, air, and land	Ministry of Environment, Forestry and Tourism - MEFT
National Solid Waste Management Strategy	Solid waste management	Ministry of Environment, Forestry and Tourism - MEFT
Seabird and Seals Protection Act 46 of 1969	Impacts on birds and seals	MFMR Directorate of Resource Management

11. CONCLUSION

The objectives of the Environmental Management Plan (**EMP**) was to formulate measures which are to mitigate adverse impacts on various environmental components, which have been identified during the environmental impact assessment study to ensure that the receiving environment is protected.

This EMP forms an appendix to the EIA Report for the finfish cage culture project; therefore, the EIA report should be referred to for further information on the project, assessment methodology, applicable legislation and assessment findings.

The EMP is to be considered as a live document and should be reviewed at predetermined intervals, and/or updated when the scope of works alters, or when further data/information can be added. All personnel working on the project will be legally required to comply with the standards set out in the EMP and per EMA of 2017 and EIA Regulation of 2012.

The EAP will avail himself to support and guide the Proponent during the construction phase both onshore and offshore. The focus of this EMP is to provide the Proponent with guidelines to be followed during the construction and operational phases for the proposed fin-fish cage culture both offshore and onshore.

In conclusion – it is all about good management and implementing best practices and complying to the regulations that will make this project become a success.

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13. APPENDICES

Appendix 1: Provides a Table that can be modified by Lilongeni Fish-Farming (Pty) Ltd. to monitor the major parameters on a daily, weekly, monthly and / or yearly basis.

Identified Aspect /	Impact description	Proposed mitigation. measures	Management and monitoring required	Duration / interval	Responsible persons

Accumulation of organic material below the net cages	Possibility of 'mounds' occurring over time below the net cages	Ensure that overfeeding does not occur	The sea-bed to be monitored / surveyed by experts divers bi-annually	Bi-annually	Ecologist
Escapees / wild fish interaction	Disease transmission and genetic alternation	To check with a rubber duck daily the cages	To monitor cameras attached to the cages	Daily	Fishery Biologist and Technician

Appendix 2: Gannt chart for a monitoring programme for a period of 5 years.

Monitoring method	**Months**											
	Jan	Feb	March	April	May	Jun	July	August	Sep	Oct	Nov	Dec
e.g. Biodiversity motoring survey												
e.g. Water quality monitoring for dissolved oxygen												