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ASSESSMENT OF EFFECTS ASSOCIATED WITH WASTE LOSSES FROM PROPOSED OFFSHORE CAGE FISH FARMS IN THE SEYCHELLES

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REPORT

Golder Associates

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1.0 INTRODUCTION

The Seychelles Mariculture Master Plan (MMP) proposes the development of fish cage aquaculture off the Inner Islands', of the Seychelles (Mahé, Praslin, La Dique, Silhouette and North Island). The Inner Islands are situated on the granitic Mahé Plateau, which forms the northern crescent of the Mascarene ridge. The area is considered to be particularly attractive for cage aquaculture. It is intended the MMP guides the development of a mariculture (aquaculture) sector in the Seychelles which includes land based aquaculture facilities along with inshore and offshore aquaculture including the identification of Aquaculture Development Zones (ADZs).

The MMP has progressed on the basis that it conforms to international best practice, the Ecosystems Approach to Aquaculture (EAA) development and principles of sustainable development. The FAO EAA (FAO 2010) responds to three principles:

- Aquaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience capacity.
- Aquaculture should improve human well-being and equity for all relevant stakeholders.
- Aquaculture should be developed in the context of (and integrated with) other relevant sectors.

The focus of this report[1] is to:

- Assess potential environmental effects that informs environmental management of cage fish farms within the current suite of identified ADZs.
- Describe waste management at the two onshore facilities and long term management of waste as it relates to fish processed from the ADZs.
- Identify elements of environmental monitoring that assist in environmental management.

A pilot fish cage site is also proposed at Providence close to the Broodstock Facility. The information presented in this assessment also applies to this pilot fish cage site.

2.0 THE SEYCHELLES MARICULTURE MASTER PLAN

The MMP guides the development of aquaculture on land, in inshore areas, within ADZs and in the offshore environment. The focus of this report relates to the key supporting facilities located on land and the ADZs.

Land-based zone

As part of land-based aquaculture, a Research & Development Facility and Broodstock Quarantine & Acclimation Facility will also be built on Mahé. Both facilities will be multipurpose buildings and will be important for sustainable growth and development of the MMP. These facilities are described further in Section 6 of this report.

Aquaculture Development Zones

This zone refers to finfish cage culture within identified ADZs of the MMP. Cages are serviced daily from land and occur at a distance greater than 2 km from inhabited islands. The proposed ADZs were selected following a hierarchical site investigation. A selection process was utilised to identify possible sites for cage fish farming. The site selection process utilised a wide and diverse range of factors based on a range of international studies to isolate suitable sites for fish farming. The primary ADZ selection criteria relating to environmental impact assessment as set out in SFA (2016) are summarised in Table 1.

[1] This report is subject to the limitations outlined in Appendix 1.

Table 1: Key ADZ environmental selection criteria (modified from Table 1 of SFA 2016).

Selection criteria	Criteria	Reason
Bathymetry (seabed profile)	Flat or low profile areas	Preferred for cage moorings
Water depth	Range 25 m to 65 m	Min. free water depth below cages >10 m
Distance from shore	>2 km from inhabited islands, where appropriate.	Open ocean cage culture minimizes impacts, minimises visual effects.
Seabed type (physical type)	Non – depositional (physically coarse e.g., sand). Potentially higher assimilation capacity.	Depositional environments are typically fine)
Seabed type (habitat)	Not ecologically sensitive	
Ecological restricted areas	Marine protected areas	High conservation areas (national parks etc.); coral reef areas

The initial bio-physical scoping exercise identified 16 potential ADZs around the inner Seychelles islands with an approximate total surface area of 61 km^2. Those potential sites were selected based on several limiting criteria including a 2 km exclusion zone around the coast of inhabited islands, a 1 km exclusion zone around Marine Protected Areas (MPAs), mitigating visual impact, avoiding conflict with the sport diving sector and artisanal fisheries, avoiding restricted areas such as shipping lanes and fibre optic cables, selection of areas with a suitable sand dominated seabed, avoiding coral reefs and seagrass meadows and other sensitive areas, choosing areas with a suitable depth and bathymetry and seeking partial protection from the southeast monsoon (SE monsoon) winds.

Of the original 16 ADZs, four were rejected, mainly because of the presence of coral reefs. The other 12 zones have a sand dominated seabed and were not affected by the exclusionary criteria (Note in Section 3.1 comment is provided regarding contradictory information about seabed type). The 12 identified zones provide a total of 53.2 km^2 for the initial development of the ADZ industry, and are identified in Figure 1.

Eight of the 12 sites are relatively well sheltered from the SE monsoon, one is partly sheltered (site PLD4) and three are not protected (sites PLD5, M1 and M54). A sheltered and protected site will be less exposed to stronger waves and currents that could develop during the SE monsoon, but are expected to result in lower waste dispersal and environmental impact, improved fish welfare and a better product quality.

Based on the FAO site classification guide and the limiting criteria for offshore cage culture in the tropics (Cardia & Lovatelli 2015; Table 3), as well as the average and maximum oceanographic conditions of the Mahé plateau obtained through the MMP field survey, related reports and literature, the site selection report concluded that fish cage culture is considered to be feasible around the inner islands of the Seychelles.

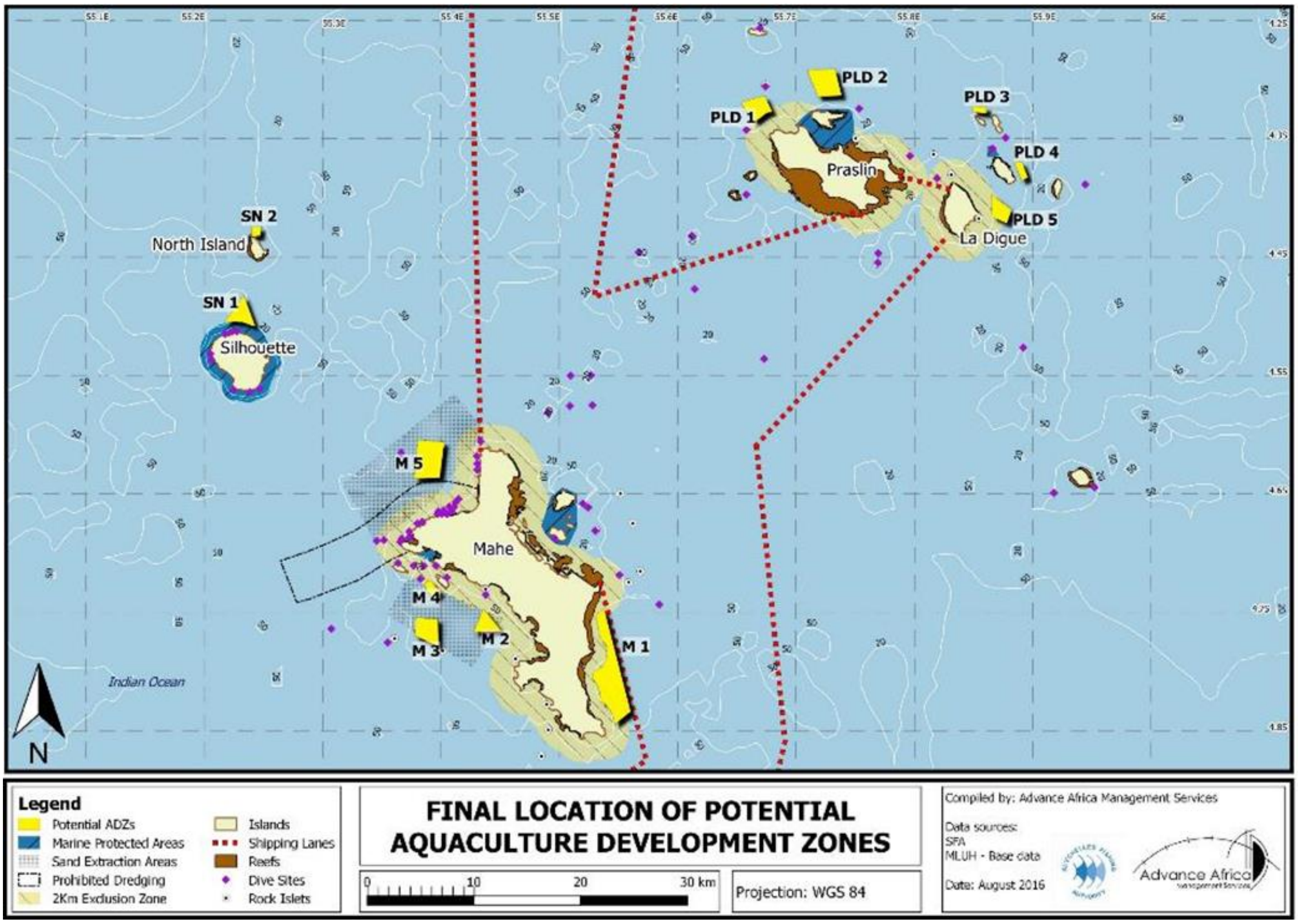

Figure 1: Location of potential ADZs (from SFA 2016).

3.0 PHYSICAL SETTING

3.1 Seabed

The nature of the seabed around the Seychelles is a function of water depth, currents and geology, amongst other factors. During the site selection process for the ADZs, a number of underwater surveys were undertaken to provide information on the nature of the seabed to assist in the selection process (refer SFA 2016). The final 12 ADZs had sand dominated seabed.

Seabed physical characteristics have been described by UNEP (2008) and Vasco (2009). The finding about the sand-dominated sea bottom around Mahé Island in the current ROV (remote operated vehicle) surveys as well as the sand mining areas as identified by Vascoe (2009) contrasts with previous geological mapping of the area that determines muddy sediments as the primary sediment type (UNEP 2008).

Much of the sandy seabed varies between carbonate (coral) sands and mineral sands. Typically, the sandy sediments are low nutrient or organic matter (Vascoe 2009). Mineral sands are dominated by quartz with about 10 % of shell-debris and carbonate substances and less than 10 % of fines (fraction <0.063 mm).

Vascoe (2009) also reported that the deep-water sand-flat areas are surrounded by carbonate-rich greenish silt-deposits, with an organic odour. It is likely that these deposits are in deeper waters (e.g., greater than 60m deep).

Based on the ROV survey video and still images, it is assumed that all ADZs have been correctly identified as having sand dominated substrates. Table 10 in Golder (2016b) provides a summary of the physical features of the 12 final ADZs. The summary identifies seabed substrate as fine to medium sand in nine site with the reminder having coarser sand and shell grit.

The key outcome in the assessment of physical seabed characteristics for each ADZ is the presence and or proximity of soft (silt or mud) sediments down current from the cage farm locations. It is recommended that the nature of substrates be confirmed.

3.2 Oceanography

Physical oceanographic factors influence the dispersion of any waste or materials lost from fish cage farms. Although farms are constructed and placed in locations that limit stresses on the cages, the environment at the cage needs to have certain depth, current and wave characteristics to ensure that materials and contaminants do not accumulate under or close to the cage/farm through deposition and sufficient dispersion is available to minimise offsite effects.

The key characteristics of the Seychelles oceanographic environment are:

- There are two monsoon-seasons – SE monsoon (June to October) and northwest (NW) monsoon (November to May). Vascoe (2009) notes that calm conditions can amount to a reasonable proportion of time, being 12 % to 27 % of the time, NW and SW of Mahe Island.
- Wave height influences potential disturbance of seabed sediments. Critical water depths for seabed disturbance are of the order of 16 m (yearly average wave) and 26 m (for the yearly maximum storm wave). As such, no sand transport would be expected under yearly average or storm waves.
- During the NW monsoon offshore waves generally approach from a north to north east direction with a significant wave height (Hs) of 1.2 m, and only 9.5 % of the waves greater than 2 m high. During the SE monsoon, waves are predominantly from a south to south-east direction and the significant wave height is higher (average Hs = 2.16 m with peaks up to 2.4 m) (SFA 2016). A maximum wave height of between 4 m and 5 m is experienced during the south east monsoons for short periods (about 0.5 % of the period from 2001 to 2004). Figure 2 illustrates typical wave heights.
- Tide and current maximum velocities around coastal areas of the Seychelles where velocities have been measured are 0.8 m/s. As described by Golder (2016a), average tidal currents are of the order of 0.30 m/s and slack tide currents around 0.05 m/s.

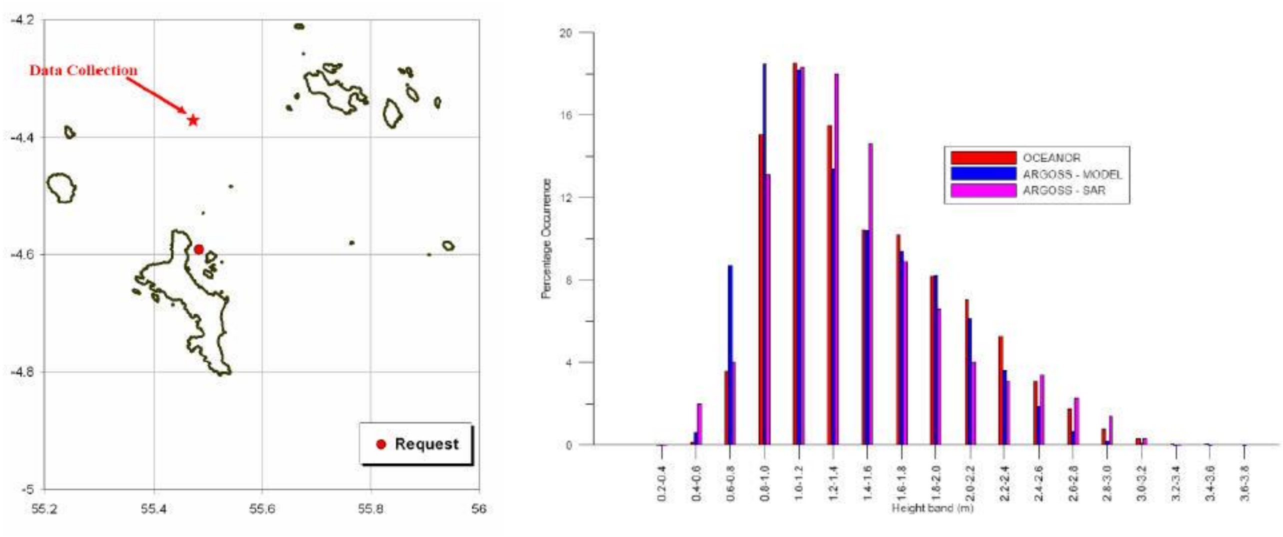

Figure 2: Wave height statistics (for 2007 year) derived from satellite data (taken from Figure 2-18 in SFA 2016).

3.3 Water Quality

There has been limited water quality information collected within the Seychelles EEZ. Data for sea surface temperature are available and suggest waters are well mixed. Salinity data indicate that offshore waters have oceanic salinities and do not vary much. It is expected that localised decreases in salinity occur in nearshore areas adjacent to freshwater sources (refer section 2.3.4 in SFA 2016 and Golder 2016a). Vascoe (2009) reported on data collected at 23 stations on the East Coast (near Ile Aurore). The information is not described here as it includes inshore and lagoon locations and the data as presented contains both unit and concentrations that are difficult to interpret based on likely water quality.

The absence (or very little marked) of vertical variation in seawater temperature in field work undertaken for ADZ selection (refer Golder 2016b) suggests that waters around the Seychelles appear to be well mixed vertically.

4.0 POTENTIAL EFFECTS OF ADZ OPERATIONS

4.1 Introduction

As noted in the introduction, the Seychelles aquaculture plan, is based on the "ecosystem approach to aquaculture".

"An ecosystem approach to aquaculture (EAA) is a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity and resilience of interlinked social-ecological systems."

One of the key components of the EAA, is that often due to the lack of information on the functioning of coastal ecosystems, there is a need for a precautionary and adaptive approach (FAO 2010). FAO (2010) identify a number of Principles in relation to developing aquaculture. Principal 1 states that developments need to take into account ecosystem functions and services. They note that this requires identification of assimilative capacities and production carrying capacities and adapting aquaculture practices as required.

The key identified water column environmental issues ascribed to cage fish farming are:

- Nutrient and organic enrichment of receiving water.
- Contributions to enhanced coastal productivity (i.e., phytoplankton growth).
- Decreases in dissolved oxygen (DO) concentrations.
- Changes in turbidity and water clarity.

The key identified benthic environmental issues ascribed to cage fish farming include:

- Generation of anoxic sediments.
- Modification to habitat and benthic communities (biodiversity changes).
- Release of chemicals used as antifoulants, in feed and for disease control.

These environmental issues are described in the following sections 4.2 and 4.3.

4.2 Water quality

4.2.1 Introduction

Price et al. (2015) and Price & Morris (2013) review available literature on the effects of fish cage aquaculture (around the globe) on water quality. Holmer (2010) who reviewed current literature on environmental effects associated with cage fish farms and found none that detected significant enrichment to the water column at offshore farms. However, the author did note that there are limitations (e.g., detection limits, methods etc.) in many studies that restrict the interpretation of results.

4.2.2 Nutrients

Nitrogen

Fish cage aquaculture releases dissolved and particulate nitrogen through losses of uneaten food, faeces and metabolic wastes (that include dissolved nitrogen in the form of ammonia and urea. A number of studies have provided estimates of nitrogen loss (relative to the amount added through feed). These studies include:

- Norði et al. (2011) calculated that about 63 % of total nitrogen fed to rainbow trout (*Oncorhynchus mykiss*) at a farm in the Faroe Islands was lost as dissolved nitrogen.
- Islam (2005) reported that 68 % to 86 % of the nitrogen input as feed is eventually released to the environment.
- Alston et al. (2005) estimated that for marine cage culture of mutton snapper (*Lutjanus analis*) and cobia (*Rachycentron canadum*) some 79 % of the nitrogen fed to the fish was released into the water.
- Bouwman et al. (2013) estimate (using modelling) that 36 % of the nitrogen in feed is retained in cultured salmon and trout, with 54 % lost as dissolved waste and 10 % as particulates.

There are a number of studies that have not identified increases in dissolved inorganic nitrogen (DIN) concentrations (refer Price et al. 2015). These studies have included a range of fish species in locations from Hawaii, Bahamas and India. However, with increased biomass of fish within cages, normal metabolic processes in the fish and the loss of even a minor portion of feed must result in a flux of nitrogen from the cage to the surrounding water. There are a wide range of factors that determine the flux and whether the flux (or dispersed concentration) will be measurable compared to the local flux.

Nitrogen flux from fish farms (and other sources) can be traced using stable nitrogen isotopes. Garcia-Sanz (2011) examined nitrogen isotopes to assess the spatial pattern and scales of nitrogen dispersal from two fish farms in the Mediterranean Sea and one in the Atlantic. The Canary Island farm stocked sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) and the others Atlantic bluefin tuna (*Thunnus thynnus*) and sea bream. In the Canary Islands, the maximum distance obtained for detection of fish farm wastes was between 450 m and 700 m and at one of the Mediterranean locations (Murcia) fish farm waste influence was detectable between 1,550 m and 2,450 m. At the other Mediterranean farm (Catalonia) the distance was less than 120 m. The short distance was considered to be due to other sources making the trend undetectable.

Also shown by Perez (2008), fish farm activities were closely reflected in the biochemistry of epiphytes and tissues of the seagrass *Posidonia oceanica* including total nitrogen content and ∂15N along with the total phosphorus concentration in rhizomes and epiphytes. Elevated ∂15N signatures were measured 2.8 km SW of the fish farm.

Effects of nitrogen loss from marine fish farms is dependent on the nature of the local/regional nitrogen fluxes (i.e., what contributes nitrogen to the coastal zone – namely, marine sources, terrestrial sources including wastewater discharges, current contributions from the fishing industry (waste disposal at sea etc.). Salmon farming operations such as in the Huon Estuary in Tasmania have been shown by Wild-Allen et al. 2010) through modelling to contribute 14 % of nitrogen flux generated in the region influencing trophic status. This Tasmanian study demonstrates that fish cages can contribute to the regional nitrogen pool but, site specific oceanographic conditions determine specific local changes.

The most significant time for nitrogen and phosphorus losses are during the spring and summer when natural marine phytoplankton will be utilising nitrogen and phosphorus for growth. Increases to the nitrogen and phosphorus pool will reduce the potential local pool in the photic zone from being depleted.

Phosphorus

Price et al. (2013) summarised studies that reported on phosphorus in the discharge from cage fish farms. Ten studies reported no significant changes (even though a measureable increase may have been detected), seven reported minimal change and seven more reported significant increases. Increased concentrations of dissolved reactive phosphorus (DRP) have been reported in studies of barramundi farming (McKinnon et al. 2008), sea bream and sea bass (Matijevic et al. 2009, Tsagaraki et al. 2011) but in all cases detected changes (typically within a few hundred metres) were not considered to result in environmentally significant increases in concentration.

There are a range of studies that have identified significant changes in DRP (or other forms of P) concentrations that depended on farm location, species farmed and feed (refer review by Price et al. 2013).

Overall, changes in down current DRP concentrations will be site specific and the extent of effect on phytoplankton or benthic algal growth and production will depend on season, water temperature and the nutrient status of local waters (i.e., whether nitrogen is limited etc.) as to whether phosphorus release to the water column has identifiable effects.

Algal blooms

Algal blooms (including harmful algal blooms) have been identified around the Seychelles. A range of studies (field measurements (at a diverse range of cage fish sites) and a range of modelling) have not demonstrated impacts (as measured by chlorophyll-a increases) from the additional nutrients from caged fish farms in adjacent environments (see Price & Morris 2013). As described by Price et al. (2015) a number of studies have shown that the nutrients contributed by cage farms can contribute to the flux of both N and P and that the flux can be manifest in growth of alga (phytoplankton, alga on fixed plates, macro-algae).

Several studies have identified increased phytoplankton biomass (as chlorophyll-a) at distances of 1,000 m (Modica et al. 2006) and further (Pitta et al. 2005). Sara et al. (2011) reported that expansion of cage farming (sea bream, sea bass and tuna) in the Sicilian Gulf contributed N and P amounting to 17 % of the N and 34 % of the P inputs per year. This was reflected in an increase in chlorophyll-a concentrations. As Price et al. (2015) point out this study is relatively unique in detecting changes at a regional scale.

Harmful algal blooms (which generate cytotoxins) have the potential to adversely affect or kill fish in aquaculture cages or biota in natural habitats. Harmful algal blooms occur in response to a complex number of factors. The cause of the harmful bloom that occurred around the Seychelles in 2015 is not known with certainty. That bloom (identified as *Cochlodinium polykrikoides*) affected wider areas of the Indian Ocean archipelago. Overall, there is little, if any, direct evidence in the literature that directly links nutrient releases from offshore cage farms to harmful algal blooms.

4.2.3 Dissolved oxygen

Effects on water column dissolved oxygen (DO) concentrations are determined by cage fish respiration and any additional (post baseline changes) oxygen demand arising from benthic sediment effects. Additional fish biomass will result in additional oxygen consumption from water passing through the cage environment.

There appears to be no published water quality data that indicates that cage fish and or benthic ecosystem changes result in detectable or environmentally significant changes in DO concentrations. Price et al. (2015) noted that a number of authors identify 'concerns' that fish cages may result in short term changes in DO concentration. That review summarised studies identifying no-effects and measurable changes (decreases) in concentration. The studies identified in the review showing decreases included seabass cages in Turkey and barramundi in Australia. In these and other studies, the decreased DO within cages were not considered to be adverse to either the cage or local environment.

4.2.4 Turbidity and water clarity

Particulates in suspension is considered a potential environmental issue as turbidity influences light penetration within the water column and hence photosynthesis. However, turbidity or water clarity is not measured in many studies. In those where it has been measured, some local (within cage or adjacent to cage) differences have been identified, but have not been considered to be environmentally significant (Price et al. 2015).

4.3 Benthic Sediments and Habitat

4.3.1 Introduction

Cage fish farms have the potential to influence the nature of the seabed sediments under and down-current from the cages, if any dissolved or particulate matter released from the farm operations reach or contact the seabed. The potential and actual effects of coastal aquaculture including fish cages, have been reviewed extensively (e.g., Keely & Morrisey 2013). Effects assessed and reviewed include:

- Changes in the composition of sediments.
- Changes in light climate under and adjacent to cages and associated infrastructure.
- Deposition of organic matter (including fish waste and fish feed) and consequent biogeochemical changes.
- Deposition of organic matters and debris from cage (biofouling) cleaning.
- Contamination of sediments (by additives etc.)

4.3.2 Changes in sediment composition

Physical changes in sediment texture under and adjacent to fish farms are unlikely to occur as farms do not typically contribute inorganic particulates (sand size or less in size) to the seabed. The majority of material contributions are organic and occur through the addition of fish waste, faecal matter, or uneaten feed.

The additional of biofouling materials from net cleaning have the potential to add shells that may add coarser materials to sediment below the cages. However, the dominant additions are organic in nature that may increase the amount of fine organic matter in the sediment.

The primary effects of sediment characteristic changes due to the addition of material from cage cleaning and waste materials are ecological in nature. These include changes in habitat from shell material deposition and changes in faunal composition arising from negative biogeochemical changes (e.g., production of anaerobic conditions).

4.3.3 Changes in underwater light climate

Shading by cages and structures will reduce light under and around the cage. The relative effect is dependent on the water depth, the size of the cages and prevailing water clarity. Some shading will occur irrespective of the size of the cages.

Reduced shading will have some effect on the growth of sessile algae, corals and or seagrasses that may be present (any biota that utilise photosynthetic processes). As such, shading issues only become significant where the cage sites within a farm may lie over sensitive habitats or biological communities (this potential should have been reduced through the ADZ site selection process).

Effects on phytoplankton are unlikely as they will pass through the shaded water for only a short period of time.

4.3.4 Deposition of organic matter

From fish and feeding

The formulated diets provided to sustain increased production are the ultimate sources of the loading of organic material. Some loss due to uneaten food is inevitable and difficult to quantify; some loss is due to the breakdown of pelleted feed to particles too small for the fish to consume. Fish meal contains fines (i.e., very small particles that caged fish are not able to consume) but these are likely to be a small component of the total feed.

As the unconsumed part of the feed is organic matter, it has a relatively high biological oxygen demand. As such, loss to water and incorporation into sediment (following deposition) has potential to result in oxygen consumption.

The amount of uneaten fish food varies considerably between studies. The feed losses are a function of the nature of the feed, application method, cage fish density etc. As an example, Penczak et al. (1982) observed loss estimates of 27 % and 31 % for dry and moist feeds respectively, for trout cultured in net cages. Not all of the lost feed reaches the seabed. Hakanson et al. (1998) also show that direct uptake and elimination processes (DUEL) account for over 90 % of particulate and dissolved effluents from fish cages. Vita et al. (2004) concluded that the natural fish population under fish cages have a role in recycling the organic matter lost from cages. The authors showed that 80 % of the particulate organic matter leaving the rearing cages may be consumed by wild fish before it settles on the seabed.

Low level fluxes of organic material can have both positive and negative impacts on the biodiversity of fish habitat, depending on habitat type and the resident species. However, at high rates, it is generally accepted that the flux of organic material to the seafloor is likely to cause a harmful alteration in fish habitat, a reduction in biodiversity, and changes in benthic species composition.

The most commonly used model of processes leading to the deposition of particulate wastes from marine finfish aquaculture is “DEPOMOD” (Cromey et al. 2002; Chamberlain et al. 2005). DEPOMOD is used to predict organic carbon deposition rates resulting from feed wastage and fish faeces production. Although the relationship between carbon flux and the level of total dissolved sulfides in marine sediments is complex there is a relationship between these parameters (DFO 2012).

Figure 3 illustrates the relationship between carbon deposition rates and the probability of anoxic conditions occurring under fish cages. The DFO (2012) DEPOMOD data indicates that at low carbon deposition rates (<5 $gC/m^2/d$), aerobic conditions prevail and the probability of anoxic conditions occurring is low. Under higher carbon deposition rates, there is a much higher probability of anoxic conditions occurring. As such, the DEPOMOD settlement rates provide useful broad scale indications of the potential for negative environmental effects to arise from carbon deposition. Carbon deposition rates can subsequently be related to fish stocking rates.

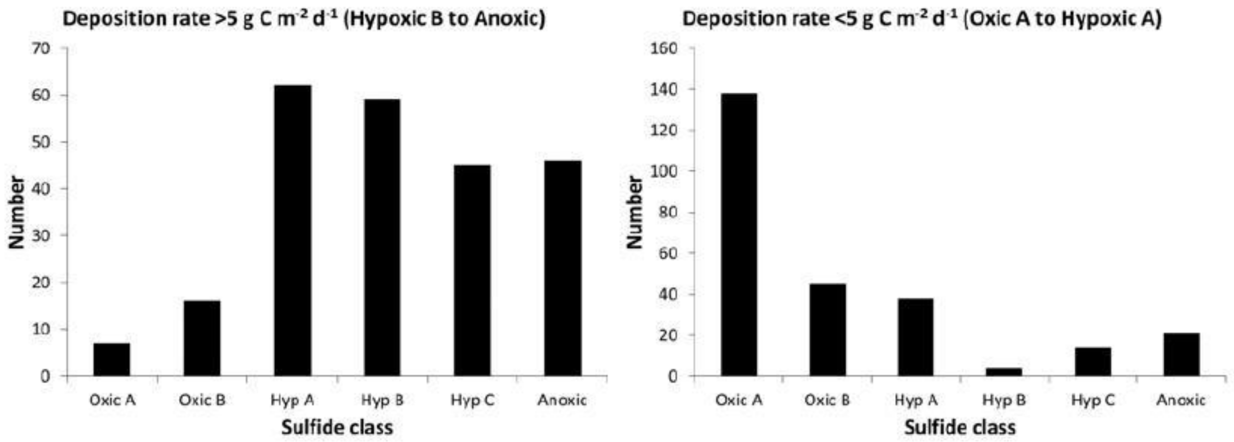

Figure 3: Left: Sulfide concentrations for DEPOMOD predictions >5 gC/m²/d. Right: Sulfide concentrations for DEPOMOD predictions <5 gC/m²/d (hyp = hypoxic) (Figure from DFO 2012).

From cage cleaning

SFA (2012) reported that biofouling rates in the Seychelles is considered low. The loss of biofouling from cage cleaning however has the potential to:

- Alter habitat under cages (through the deposition of shell material).
- Add organic matter to sediment effecting basic sediment biogeochemical properties (especially reduction-oxidation (redox) conditions).

4.3.5 Contamination of sediments

A limited range of additives are utilised in cage fish aquaculture. Internationally these have included:

- The use of copper and zinc in antifoulant paints and feed (additives).
- Antibiotics and parasiticides.
- Disinfectants and detergents.
- Rubbish and debris.

Trace elements

Copper is the most common element used in antifoulants which may be applied to cage nets. Antifoulants are used on fish cages in a range of countries. Clement et al. (2010) determined that 21 % of the copper agent from the original coating of a net entered the marine environment (with an annual usage per farm in the range 230 kg to 700 kg). Elevated copper concentrations have been found in sediment under fish cages using copper antifoulants and at concentrations higher than the ANZECC (2000) ISQG-High trigger value of 110 mg/kg.

Zinc is present in feed as a nutritional additive with concentrations of up to 100 mg/kg reported. Any zinc not utilised by the fish or lost in fed is excreted and enters the environment under and downstream of the cage. Elevated concentrations of zinc in sediments under and adjacent to cage sites have been reported (e.g., Keely & Morrisey 2013). The concentrations in those situations exceed the ANZECC (2000) ISQG-High sediment quality trigger values for zinc of 410 mg/kg, indicating that there is a high probability of zinc potentially resulting in adverse effects on infaunal biota at those sites.

Therapeuticals

The need for therapeutants is dependent upon the incident and type of disease that requires management. With an expanding industry the type of parasite or disease management required may only be confirmed following start up and growth of the industry.

The significance of therapeutant use is dependent on their environment fate when entering the environment (dissolved or in feed). Environmental fate is dependent upon the solubility of the compound. As such, the loss of residual amounts of compounds to the water and sediment below and down-current of fish cages has potential implications, in particular to the well-being of natural bacterial populations in sediment below cages (e.g., antibiotic resistance). For more detail refer Champeau & Boustead (2013).

Detergents

Detergents lost to coastal waters can potentially have adverse effects at a cellular level in marine biota. Key effects are likely to be local and short term (especially if water soluble and biodegradable products are used).

Rubbish & debris

The loss of rubbish from cage farming operations has a range of potential effects. Debris and rubbish may include:

- Paper and plastic waste from workers at cages.
- Discarded equipment.
- Organic fish waste, dead fish and cage biofouling (refer above).

Loss of plastics, in particular, can have a multitude of effects including negative effects on marine biota due to ingestion, entanglement (if plastic net or rope etc.) and the addition of organic compounds as the plastic degrades. The latter may contribute compounds such as phthalates and bisphenol and to sediment and water.

5.0 ASSESSMENT OF EFFECTS OF ADZ OPERATIONS

5.1 Introduction

This section reviews the information presented in Section 4 in relation to the proposed ADZs in the Seychelles. Two specific assessments have been undertaken in relation to the effects of fish cage culture on the production of waste and effects arising from the deposition and loss of that waste material. These are:

- As assessment of the loss of fish waste and effects utilising the Norwegian MOM (modelling – outgrowing – monitoring) model (SFA 2016).
- An assessment of the dispersion of particulate materials from fish cages using the information provided in SFA (2016) undertaken by Golder (2016a).

5.2 Waste Generation from ADZs

SFA (2016) undertook modelling using the Norwegian MOM model, calibrated for grouper fishes, in order to assess carrying capacity of the ADZ sites for finfish aquaculture. The model was run for three different water depths (25, 35 and 55 m), each with a best, mid and worst case scenario and physical parameters varied accordingly (current standard deviation, DO in bottom layer, dimensioning current surface layer, dimensioning current bottom layer, lowest acceptable DO in cages, lowest acceptable DO at the bottom and food conversion ratio.

The worst case scenario release rates of fish faeces and food pellets in the MOM assessment undertaken by SFA (2016) were based on a total of 236 kg of faeces produced and 671 kg of wasted food per ton of fish production (see Table 21 in SFA, 2016).

The MOM model predicts that the maximum annual production of fish that can be sustained under all scenarios is 42.92 tpa/ha, a rate approximatively four times higher than the proposed precautionary production limit of 10 tpa/ha. The MOM modelling presented in SFA (2016) does not predict a carbon flux to the sediment (i.e., it is identified as 0 g C m^2/yr).

The conclusion of the MOM work undertaken by SFA (2016) is that a significantly higher production capacity than the precautionary limit (>4 times greater) provides some degree of confidence that the proposed production limit is conservative given the amount of site specific data that was available. Even though the conclusion was considered to be conservative, SFA (2016) recommended that a precautionary production limit of 10 tonnes/year/Ha limit should not be exceeded until actual farm monitoring data become available that may support an increase in the rate of production per unit area.

SFA (2016) proposes that further environmental assessments and long-term monitoring should include video-recorded observations of benthic substrates, hydrographic information, water quality measurements, sediment analysis, and benthic community assessment. Sampling and data collection must occur at intervals that capture seasonal variation in circulation, water quality, and other environmental characteristics. The aquaculture permit should clearly define the frequency, format, content, and distribution of monitoring reports and identify which agency shall review the reports (Price & Beck-Stimpert 2014). Monitoring is discussed further in Section 7.

5.3 Dispersion of Waste from Fish Cages

Golder (2016a) undertook modelling of faeces and waste feed from ADZ cages using the Flow-3D hydrodynamic model (including particle tracking). The study examined four scenarios:

- Sim01: Faeces transport with weak ambient current (5 cm/s) and typical wind.
- Sim02: Faeces transport with strong ambient current (30 cm/s) and monsoon wind.
- Sim03: Uneaten food transport with weak ambient current and typical wind.
- Sim04: Uneaten food transport with strong ambient current and monsoon wind.

The purpose of using a purely physical approach is to provide a preliminary and conservative assessment of particle dispersion around a given cage site under minimum and maximum conditions in terms of wind and current speed. As noted in Golder (2016a), the assessment should be regarded as the initial step toward a more comprehensive assessment of aquaculture waste trajectory, fate and effects on the marine ecosystem of the inner Seychelles. The model did not include non-particulate components of effluent or the potential resuspension of particles on the seabed nor the direct consumption of faecal and feed particles by fish and other biota in the water column and on the substratum. Modeling that included these other factors would improve the confidence in the model predictions.

The trajectory of uneaten food and faecal matter wastes were assessed for covering a size spectrum ranging from juvenile fish with food and faeces of 2 mm diameter to adult finfish with food and faeces of 10 mm diameter. Figure 4 illustrates modelled dispersion of faecal pellets down current from a cage.

For every model scenario, approximatively 85 % of the initial food or faeces release settled to the seafloor within the time-window of the simulation. The remaining 15 % fraction is expected to be further advected and dispersed in the water column without having any significant impact on the marine environment. Golder (2016a) notes that the model does not take into account degradation and dissolution processes, and as a result the flux to the seabed and water column dispersion provided are considered conservative.

The carbon flux estimates from Golder (2016a) are considerably lower than the threshold carbon flux estimated by DEPOMOD (DFO 2012). The combined worst case flux in the Table 2 estimates are less than 0.05 g C/m^2/d. If the calculated fluxes of carbon reflect the anticipated flux, the additive organic matter to the seabed under the cages is expected to be small. Price & Morris (2013) summarise literature on carbon deposition rates from cage fish aquaculture. Rates differ by two orders of magnitude are determined by a range of factors (stocking rates, environment etc.). Carbon deposition rates are often in the gram/m^2/d rate (as shown in Figure 3). However low deposition rates have been identified through modelling in offshore environments. Doglioli et al. (2004) used modelling to find that a cage site in the Ligurian Sea (sea bream and sea bass) would add about 0.085 g C/m^2/day. The site was located offshore in 40 m of water with strong water currents.

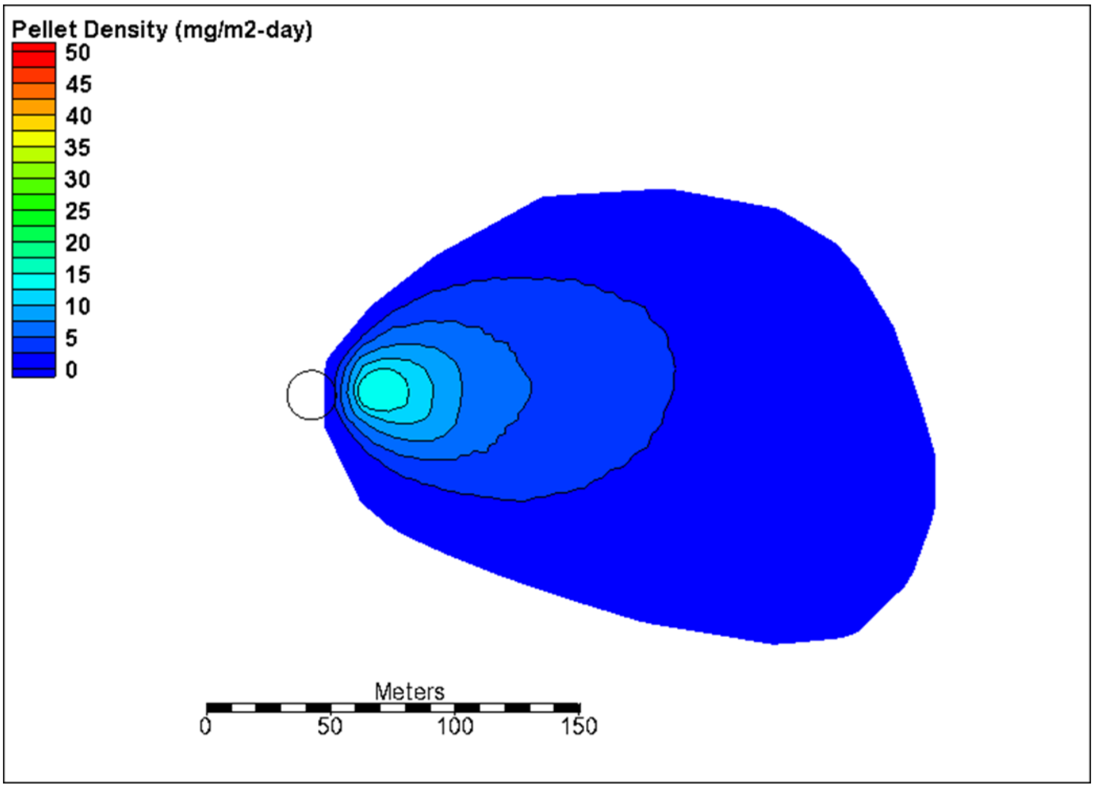

Figure 4: Seabed accumulation of faecal particulate matter under strong current conditions (From Golder 2016a).

Table 2: Maximum accumulation rate of fish faeces and uneaten food pellets at the seabed.

Particle	Ambient conditions	Maximum particulate flux to the seabed (mg m^{-2} d^{-1})	Maximum carbon flux to the seabed (g C m^2/d)
Faeces	Weak wind and current (Sim01)	0.0239	0.0064
Faeces	Strong wind and current (Sim02)	0.0134	0.0038
Uneaten food	Weak wind and current (Sim03)	0.051	0.0229
Uneaten food	Strong wind and current (Sim04)	0.0355	0.016

The Golder (2016a) study provides an indication that the seabed deposition area of influence is expected to be in the hundreds of metres. However, based on the flux, the relative changes will be focused below the cages (vertically), with minor changes occurring horizontally away from the cages.

5.4 Seabed Effects

Seabed habitat

Changes in seabed habitat characteristics under cages will only occur if deposition of carbon biomass exceeds the under-cage environments natural ability to process feed waste and fish excreta waste.

Should biofouling levels on cages be higher than predicted, more biomass may be lost to seabed than expected. Physical habitat changes can occur if shell is added from cage and structure cleaning (refer Section 4.3.2). This will need to be monitored and managed as discussed in Section 7.

Sediment biogeochemistry

Seabed biogeochemistry changes will be dominated by organic matter additions and consequent changes in redox conditions should the additions be excessive (e.g., greater than the thresholds identified by DEPOMOD). Current estimates of predicted carbon deposition based on fish stocking are very low compared to the DEPOMOD thresholds described in Section 4.3.4.

Organic matter additions are controlled through a number of cage feed and waste management strategies as discussed in Section 7.

Trace elements in antifoulants and feed

Under the Special Conditions of the Seychelles Marine Aquaculture Licence for Finfish Grow-out in Cages, Section 8 (a) states, "*The License Holder shall ensure that the Regulator approves any anti-fouling product used on the net pen material*".

The needs for antifoulants is dependent upon the material used for the main structural elements of the cages. Although the special conditions indicate that antifoulants are not to be used this will need to be confirmed. If antifoulants are not used this will eliminate the potential for accrual of copper (or other antifoulants) in the seabed under cages. Feed management is discussed further in Section 7.

Therapeuticals

The Seychelles Aquaculture Standard for '*Responsible Effluent and Waste Management*' stipulate that the use of hormones and antibiotics in the Seychelles will be restricted to land-based facilities under supervision of a state veterinarian.

As described in Section 4.3.5 the need for their use may be dependent on disease occurrence. The need may need to be reviewed.

5.5 Water Column Effects

Nutrients

In Section 4.2.2 it was noted that both nitrogen and phosphorus will be released to the water column from cage facilities. The release will add to the flux of both nutrients moving downstream from the farms. The key nutrient issues that need to be confirmed are:

- What is the local change (additive change) in nitrogen and phosphorus flux (relative to the natural flux)?
- Do the changed water nutrient loads travel and intersect any sensitive environments (e.g., corals)?
- Do the cages in farms create larger plumes that may have greater additive nutrient addition?

No published water quality information appears available that provides an adequate picture of the nutrient status of Seychelles coastal waters. However, although nutrient changes downstream of cages have been identified significant changes downstream of the ADZs are not anticipated. Additional water quality data can be collated prior to ADZs coming into operation and this is discussed in Section 7.

Trace elements in antifoulants and feed

Under the Special Conditions of the Seychelles Marine Aquaculture Licence for Finfish Grow-out in Cages, Section 8 (a) states, "*The License Holder shall ensure that the Regulator approves any anti-fouling product used on the net pen material*".

The needs for antifoulants is dependent upon the material used for the main structural elements of the cages. Some loss to the water column would be expected should antifoulants be utilised. However, the relative effects are considered minor compared to sediment changes as discussed in Section 4.3.5.

No significant effects from trace elements in feed are anticipated in the water column.

Therapeuticals

The Seychelles Aquaculture Standard for '*Responsible Effluent and Waste Management*' stipulate that the use of hormones and anti-biotics in the Seychelles will be been restricted to land based facilities under supervision of a state veterinarian. As such, these are not considered further.

Decreasing the spread of diseases and, consequently, the use of parasiticides can be assisted by having cage separation requirements (refer Section 7).

Detergents

Use of low toxicity impact detergents and off-site cleaning (where possible) can reduce the impact.

6.0 LAND BASED FACILITIES AND WASTE MANAGEMENT

6.1 Introduction

A range of land based aquaculture facilities has been identified in the MMP. As part of land-based aquaculture, a Broodstock Quarantine & Acclimation Facility (BQAF) and a Research & Development (R&D) Facility will also be built on Mahé. Both facilities will be multipurpose buildings and will be important for sustainable growth and development of the MMP. This section provides background information on the management of waste at both facilities and provides commentary on the management of waste produced by the ADZs.

6.2 Broodstock Quarantine & Acclimation Facility

The Seychelles BQAF is a multi-species quarantine and acclimation facility that provides quarantine treatments for wild-caught broodstock, and prepares these fish for life and reproduction in captivity at the Anse Royale R&D Facility. The broodstock are sourced from Seychelles waters. After a certain period (depending on the species), acclimated broodstock will be transferred to the R&D Facility at Anse Royale and stocked into the broodstock tanks for spawning and egg production.

The BQAF is located in Providence, Mahe adjacent to the shore, SFA and wharf. The site is located adjacent to the shoreline providing convenient access to seawater supply which will be pumped from about 700 m directly offshore.

Broodstock facility

Seawater is pumped ashore into a header tank before being gravity-fed through a drum filter into the aquaculture systems. Two acclimation tanks (each 36.5 m^3) for grouper and other large species, and four acclimation tanks (each 13 m^3) for mangrove snapper (*Lutjanus argentimaculatus*) and sub nosed pompano (*Trachinotus blochii*) will be installed. Water supply to the tanks is on a flow-through basis, except for the snubnose pompano tanks which can also be run on a water re-circulation system.

Broodstock will be stocked into the quarantine tanks on arrival at the BQAF. They will undergo a series of treatments for a period of four to six weeks including reduced salinity baths, formalin treatments and prophylaxis. These treatments will prevent the introduction of disease / parasites into the BQAF and R&D Facility. The fish are monitored and well fed during the days without treatment at a feed ratio of 0.5% body weight per day. Feeding is conducted six days a week and fish are fed to satiation with a diet of chopped fish and squid.

Waste management at the facility

Wastewater is drum filtered before being discharged. The drum filter typically utilises mechanical microfiltration with screen panels (polyester fabric) and are often used in fish hatcheries. Screens can be manually cleaned or automatically cleaned using backwashing. The filter system ensures that un-eaten food and other particles are removed prior to the flow through water being discharged back to the harbour.

The principal change in water quality compared to incoming seawater will be the addition of dissolved nitrogen and some dissolved organic matter. The relative change will be dependent upon the biomass of broodstock held in the facility on any given day. A range of other waste will be produced at the facility which will be managed separately from the flow through seawater system. This includes:

- Collection and disposal of dead fish
- Disinfection and washing of floors and equipment
- Disposal of human wastewater

6.3 Research & Development Facility

The Seychelles R&D Facility at Anse Royale, Mahe is a multi-species tropical fish hatchery, science hub and visitors centre. The R&D Facility is located 8 km from the Mahe International Airport, and 18 km from the capital Victoria. The site is on the southern grounds of the University of Seychelles at Anse Royale.

R&D Facility

The facility is serviced by flow-through seawater obtained some 700 m directly offshore. Seawater is pumped ashore into a storage reservoir. It is then pumped into a header tank before being gravity-fed through a drum filter into the aquaculture systems.

The facility will over time provide facilities for the rearing of a variety of species. Initially, focus will be on the production of brown-marbled grouper (*Epinephelus fuscoguttat*us), mangrove snapper and red emperor snapper fingerlings

The hatchery sector of the facility comprises the quarantine, broodstock, larval, nursery and experimental aquaculture tanks as well as the live feed area. Broodstock are housed in low densities in large tanks (between 23 m^3 and 75 m^3) which allow for voluntary spawning behaviour and freedom of movement. The broodstock tanks have a daily water exchange of 250 %.

Waste management at the facility

Drainage from the tanks and facility occurs to a central channel. The flow through water is drum filtered and drained into a settling pond before being discharged into the canal. The drum filter will remove all suspended solids reducing the load to the settling pond. The pond has an area of 150 m^2. It is assumed that the pond will be designed to provide maximum retention and will be segmented to avoid short circuiting of sea water passing through it. It is also assumed that the purpose of the pond is to provide additional polishing and assist in the reduction of dissolved nitrogen from fish excreta. Macroalga uch as Ulva will assist in scrubbing nutrients.

A range of other waste will be produced at the facility which will be managed separately from the flow through seawater system. This includes:

- Collection and disposal of dead fish.

- Disinfection and washing of floors and equipment.
- Disposal of human wastewater (staff and visitors).

6.4 Fish Processing Waste Management

6.4.1 Introduction

The introduction of fish farming will introduce additional fish biomass that will require processing at land based fish processing facilities in the Seychelles. Total domestic production of fish and fish products, including the production of fish meal and fish oil recorded an increase from 104,838 Mt in 2012 to 115,429 Mt in 2013 (SFA 2013).

Fish meal is a by-product produced from the tuna factory trimmings. Fish oil is obtained during the reduction process by which fish meal is produced and are significant by-products from the tuna canning industry. Production of fish oil decreased by 20.7 to 691 Mt in 2013, while the production of fish meal increased by 11.2% to 7,337 Mt (SFA 2013). Fish and fish products represent a significant portion of Seychelles exports.

Solid waste management within the ADZs is governed by Section 7 of the Seychelles Aquaculture Standard 18 Finfish Cage Culture (S18). Solid waste as defined includes human waste, feedbags, other packaging material, scrap rope and netting, scrap buoys and weights, replaced cage parts, metal and plastic waste material, spoiled feed, mortalities, fouling organisms and any other solid waste. The standard is referred to further in Section 7. The remainder of this section deals with land based fish processing waste.

6.4.2 Fish processing

It is understood that there are five commercial fish processing facilities in the Seychelles including a large tuna canning factory (Indian Ocean Tuna (IOT)) that processes about 350 tonnes of tuna (fresh and imported) every day. This is mostly for the export market. One facility is currently located on the IOT property as it utilises by-products from IOT. Currently, fish caught at sea are partly processed at sea with much of the fish returned gutted and headed to land (and the waste disposed at sea). Anecdotal information indicates that the fish processing facilities other than the canning factory are not at capacity.

6.4.3 Waste management

The Seychelles Solid Waste Management Policy 2014-2018 sets the framework and presents guiding principles for waste management in the Seychelles and three sets of Regulations govern waste and effluent management in Seychelles. Currently, waste management at current plants varies between plants. Broadly this includes:

- Waste collected by contractor (STAR Waste Management) with solid waste disposed to landfill.
- Excess fish waste to be turned into fish meal.

Currently, there may be over several hundred tonnes of fish related waste generated each year at Seychelles fish processing facilities. Added value processes assist in reducing waste volumes going to landfill. These include (e.g., operated by Ocean product Seychelles) processing of skeletons (e.g., for collagen), production of fish oil and also production of fish meal (e.g., by IOT).

6.4.4 Effluent management

Liquid waste (blood, fish washing, cleaning) is discharged into sewerage system but some may still discharge to coastal waters. Further information on current disposal practices is required to inform wastewater management and capacity at waste water treatment plants in the future.

6.4.5 Needs and sustainability

With the development of the ADZs, fish production increases over time will result in increases in both liquid and solid waste. It is important that the predicted production increases are matched to:

- The capacity of fish processing facilities to receive the production.
- The capacity of wastewater treatment systems to receive increased volumes of liquid waste.
- The ability of secondary processing industries to receive fish waste to produce added value fish products.
- Ice production required to support the industry.

A number of information needs have been identified that should be resourced to inform the development of a waste management strategy/plan for fish processing in Seychelles. The industry waste management strategy **should examine sustainable waste management practices to reduce volume to landfill and maximise product reuse and revenue gained from fish production.**

7.0 MITIGATION

7.1 Introduction

The previous sections have identified that cage fish farming has the potential to generate both low level and potentially more significant impacts in the environments they are situated. These can be managed and mitigated in a number of ways through regulation, farm siting, farm layout and on-site farm management practices. These are discussed in this section.

7.2 Farm Management

Management at ADZs is informed by the S18. The Standard covers a wide range of farm management topics as described below.

Feeding and waste

Feed management in covered in Section 5 of S18. Improvements in feed formulation and feeding efficiency are repeatedly cited as major reasons for decreased nutrient loading and decreased impacts to water quality in and near farms. Additional feed related mitigation factors include:

- Broken pellets and dust should be sifted out before feeding, and feed systems must not damage the pellets.
- Feed should be applied in a manner to maximise its consumption by fish.
- Pellet size should be carefully matched to fish size
- Siting farms in well flushed non-depositional waters with depth at least twice that of the net pen is recommended to ensure good water quality below cages.
- Section 10 of S18 identifies sustainable aids to feed and waste losses to the seabed that include the use of polyculture to manage the loss of organic matter. This includes the culture of sea cucumber or filter feeding shellfish under the nets.

Overall, there are a wide range of identified management strategies that can potentially mitigate potential adverse environmental effects. These all focus on minimising the loss of organic matter that is deposited on the seabed.

Nutrient management

Section 4 of S18, identifies that in order "*to prevent cumulative environmental impacts, farms that produce more than 500 tonnes of fish per annum must be separated by at least 500 m. The distance between smaller farms will be determined by the Regulator on a case specific basis*".

Nutrient management (i.e., loss of dissolved nutrients to surrounding) water and cumulative coastal zone nutrient build-up is assisted by farm siting, cage positioning and the site having appropriate hydrodynamic environment (e.g., good tide and current velocities).

Debris and waste management

Section 7 of S18 sets out solid waste management and disposal management requirements for operators. The key elements are:

- The preparation of a solid waste management plan.
- Appropriate solid waste disposal (on Mahé).
- The collection of all dead cage fish.
- The avoidance of debris generation during net cleaning on site. The standard identifies the use of sustainable cleaning aids such as the stocking of grazing fish in the cages.

Debris management strategies have the potential to eliminate the loss of man-made solid waste to the marine environment and the potential to reduce biological waste to the seabed.

Seabed biogeochemical changes

In the sections above, a number of management strategies focussed on minimising the deposition of organic matter from fish feeding, fish waste and cage biofouling on the seabed. Significant changes in seabed condition are detected through **monitoring** (refer Section 7.3). The critical change is a change from aerobic surface sediments to anaerobic sediments. This change typically occurs due to the introduction of fine organic matter and excess organic matter decomposing and consuming oxygen within the sediment.

Although deoxygenation and anaerobic conditions have significant negative effects on benthic habitat and biota the effects are reversible by fallowing the site and allowing it to recover. Recovery rates from excess bio-deposition are site specific. Keeley & Morrisey (2013) report quick initial recovery (i.e., between three and 12 months) with more complete benthic community recovery in the following years. The recovery rate will be assisted if seabed disturbance due to annual storms occurs.

7.3 Monitoring

7.3.1 Aquaculture Standard 18

Monitoring is an important component of ADZ management as it informs adaptive management. Section 6 of the S18, sets out minimum monitoring requirements for operators. The monitoring is based on seabed video and seabed photography capturing the nature and condition of the seabed. Information is recorded via transects and quadrats. The Standard indicates that the images are to be of sufficient detail and clarity to allow for the accurate assessment of benthic conditions. A brief written narrative with the tape or photographs describing current speed and direction and reference points are to be prepared.

7.3.2 Environmental monitoring

A range of environmental monitoring can be undertaken during the adaptive management phase of early ADZ farm development. In particular emphasis in monitoring should be given to benthic enrichment monitoring (as identified above in relation to S18). Monitoring needs to be adapted for each site specific ADZ depending on farm layout and local physical conditions (especially currents). Table 3 below provides a useful summary of the range of variables identified by Keeley & Morrisey (2013) that can be included in benthic monitoring programmes.

Table 3: Summary of environmental variables and environmental quality standards (EQS) utilised in salmon farming in New Zealand and elsewhere globally (Table taken from Appendix 3.2 of Keeley & Morrisey 2013).

	Group		Variable	Where used	EQS use	Standards
Benthic	Physical	1	Sediment grain size	NZ, Ca, Ch, No, UK, US	–	
	Chemical	2	Redox	NZ, Ta, Ca, I, Ch, No, UK, US	US, UK, Ta, WWF	Various – spatially explicit
		3	Sulphides	NZ, Ta, Ca, Ch, No, UK, US	US, UK, Ta, WWF	Various – spatially explicit
		4	pH	Ch, No	–	
		5	Trace metals (Cu and Zn)	NZ, Ta, US	UK, Ta, NZ	ANZECC ISQG-Low-High
	Observations	6	Feed pellets	NZ, Ta, Ca, I, Ch, UK, US	Ta, I, UK	Qual. categories. High presence prohibited
	(Qualitative)	7	Out-gassing	NZ, Ta, I, Ca, Ch, No, US	Ta, NZ	Free out-gassing prohibited
		8	Odour	NZ, Ta, I, No, UK, US	–	
		9	Colour	I, No, NZ, Ta, UK, US	–	
		10	Sludge thickness	I, No, UK, US	–	
		11	Consistency	Ca, Ch, I, No	–	
		12	Beggiatoa mat	NZ, Ta, Ca, I, Ch, UK, US	US, UK, I, Ta, NZ	Qual. categories. High coverage prohibited
		13	Rubbish/debris	?	–	
Biological	Infauna	14	Abundance	NZ, Ta, Ca, I, Ch, No, UK, US	US, UK, Ta, NZ	Azoic prohibited, limits on abundance relative to reference
		15	No. Taxa	NZ, Ta, Ca, I, Ch, No, UK, US	US, UK, I, Ta, NZ, WWF	Limits on minimum number of taxa
		16	No. opportunists	?	US, Ta	Limits on total abundance of
		17	Shannon Diversity	?	WWF	Minimum diversity restrictions
		18	Evenness	?		
		19	AMBI	?	WWF	Minimum diversity restrictions
		20	Other indices (ITI, BQI)	?	WWF	Minimum diversity restrictions
	Epifauna		Non-specific use	Ca, I, NZ, Tas, US		
		21	Presence/absence			
		22	Diversity			
		23	Observed health			
		24	Aggregations			

pH = acidity; Cu = copper; Zn = zinc; NZ = New Zealand; Ta = Tasmania; Ca = Canada; Ch = Chile; N = Norway; I = Ireland; UK = United Kingdom; US = United States of America; WWF = World Wildlife Fund Draft Aquaculture standards (http://www.worldwildlife.org/what/globalmarkets/aquaculture/WWFBinaryitem21275.pdf). Summarised from Wilson et al. (2009) and various online sources.

7.4 Adaptive Management and Plans

In the development of aquaculture programmes such as that proposed, adaptive management is an important element of the establishment of the industry. The development of S18 provides an important benchmark for the development of ADZs.

Adaptive management provides the ability to alter management systems and operations as production is increased from an initial start-up rate to the planned full production rate. S18 specifies a number of operational plans that also have environmental benefits. In addition, the following should be considered:

- Development of an environmental monitoring plan and ongoing monitoring and assessment (with focus on sediment quality and benthic ecology).
- Collection of specific environmental/ecological benchmark information to inform ongoing monitoring program.
- Development of environmental thresholds and benchmarks.
- Development of environmental management plan to assist with mitigation of any identified environmental changes.

8.0 OVERVIEW OF ENVIRONMENTAL CONSEQUENCES

8.1 Introduction

The sections below present an overview of the potential impacts during the operational phase using the calculations and rating system, as provided in Table 4 and Table 5. The impact ranking matrix is applied to the environmental assessment outputs presented in this report.

Table 4: Impact ranking matrix.

Occurrence		**Severity**	
Probability of occurrence	Duration of occurrence	Magnitude (severity) of impact	Scale / extent of impact

- Note: To assess each impact, the following four ranking scales are used

Probability	**Duration**
5 - Definite/don't know	5 - Permanent
4 - Highly probable	4 - Long-term
3 - Medium probability	3 - Medium-term (8-15 years)
2 - Low probability	2 - Short-term (0-7 years) (impact ceases after the operational life of the activity)
1 - Improbable	1 – Immediate
0 - None	
SCALE	**MAGNITUDE**
5 - International	10 - Very high/don't know
4 - National	8 - High
3 - Regional	6 - Moderate
2 - Local	4 - Low
1 - Site only	2 - Minor
0 - None	

- The significance of the two aspects, occurrence and severity, is assessed using the following formula:

- SP (significance points) = (magnitude + duration + scale) x probability
- The maximum value is 100 significance points (SP). The impact significance points are assigned a rating of high, medium or low with respect to their environmental impact as follows (Table 5):

Table 5: Significance ratings.

SP >75	**Indicates high environmental significance**	**An impact which could influence the decision about whether or not to proceed with the project regardless of any possible mitigation.**
SP 30 – 75	Indicates **moderate** environmental significance	An impact or benefit which is sufficiently important to require management and which could have an influence on the decision unless it is mitigated.
SP <30	Indicates **low** environmental significance	Impacts with little real effect and which should not have an influence on or require modification of the project design.
+	Positive impact	An impact that is likely to result in positive consequences/effects.

8.2 Impact Significance Assessment

The impact on the marine environment of the activities at cage sites within ADZs was assessed as being of **low (SP<30)** to ***moderate (SP = 33 to 36)*** significance.

A range of possible mitigations measures were identified in Section 7 of this report. The Aquaculture Standard S18 provides a wide range of mitigation measures that assist in reducing/minimising potential impacts. With appropriate mitigation it is considered that activities have reduced impact with scores reducing to ***low (SP = 15 to 24)*** significance (Table 6).

The reduced impacts identified through likely mitigation are predicated on an adaptive management process being utilised to understand site specific environmental issues early in the implementation of the aquaculture program. **This process assumes that early cage installation is undertaken at low production rates (10 ton/yr/ha) prior to significant ramping of production**. Adaptive management will be assisted by monitoring of appropriate components of the environment and operations and the preparation of Operating and Management Plans as required by *Aquaculture Standard18: Effluent and Waste*.

As described by Golder (2016a) monitoring of cage site environments following start-up will be assisted by complementary modelling utilising fish farming models MOM or NewDEPOMOD. This initial comparison will assist the development of other fish cage culture sites and the use of models as a predictive tool in those locations.

Table 6: Environmental Impact Assessment Matrix for the identified key potential impacts associated with fish cage sites pre and post-mitigation.

POTENTIAL ENVIRONMENTAL IMPACT: WASTE DISPERSION FROM CULTURE CAGES	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	SP	Rating	M	D	S	P	SP	Rating
Undercage benthic effects from faeces and fish waste can impact seabed under cage and down-current	8	2	2	3	36	Moderate	4	2	2	3	24	Low
Waterborne nutrient loss can contribute to local and cub-regional nutrient concentrations in coastal waters with potential effects on phytoplankton growth	6	1	2	2	18	Low	6	1	2	2	18	Low
Sediment contaminant accumulation can occur through antifouling and from trace elements in feed	6	4	1	3	33	Moderate	4	3	1	3	24	Low
Sediment debris accumulation can occur from the loss of cage fouling during on site cleaning	4	2	1	4	28	Low	4	2	1	3	21	Low
Rubbish loss can occur through poor on-site management (introduction of recalcitrant rubbish, especially plastics)	2	1	3	3	18	Low	2	1	2	3	15	Low

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APPENDIX A

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